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TECHNICAL REPORT

Animal Effects from Soviet Atmospheric Nuclear Tests

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14. ABSTRACT
This two-part document describes the effect on animal models of atmospheric nuclear weapons tests performed by the Soviet Union at the Semipalatinsk Test Site. Part 1 describes the air blast and thermal radiation effects. Part 2 covers the effects of primary (prompt) radiation and secondary (fallout) radiation on the test subjects. It also covers combined radiation injuries, defined as a combination of radiation and non-radiation injuries. Several different animal species were used. Animals were emplaced at varying distances from the explosion's epicenter, and in a variety of terrain configurations (open ground, trenches oriented parallel and perpendicular to the blast, etc.) The protective effects of shielding from different military vehicles and buildings were also studied. The types, degrees of severity, and clinical course of illness from the injuries produced were carefully studied in order to better understand the pathogenic mechanisms of injury and the likelihood of efficacy of proposed treatment measures.

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FOREWORD

During the period of atmospheric nuclear weapons testing, both the United States and the Soviet Union sought ways to decrease the massive numbers of casualties and suffering they knew they would experience in case of nuclear war. To accomplish this goal it was necessary to develop a greater understanding of the biological effects of nuclear weapons, particularly with respect to the radiation emitted by these devices. Greater understanding of the blast, thermal, and ionizing radiation effects of nuclear weapons on biological tissues was required. The protective effects of shielding, whether from terrain, transport vehicles, industrial or residential buildings, or specially designed shelters, also had to be investigated. The need for suitable animal models to accomplish these purposes was recognized. Laboratory studies, although necessary to enhance knowledge of responses to radiation at the cellular and molecular levels, could not adequately simulate the high fluxes of both neutron and photon radiations from a bomb, the different kinds of energies simultaneously affecting the animals, nor the modification of the effects of these energies by the types of shielding that would be used in real life. Accordingly, both nations performed experiments exposing various animal models to aboveground nuclear tests.

The Soviet Union performed several experiments studying the impact of nuclear weapons on animals. Two of the most extensive experiments, in terms of numbers of animals used, types of shielding employed, and other biological questions addressed, were conducted in November 1955. The authors investigated the effects of air blast, thermal radiation, and ionizing radiation on the animals. They also dealt with the effects of ground contamination from fallout, both in terms of internal and external radiation. The tests focused primarily on three problems: (1) radiological safety for test participants and the surrounding population and its crops; (2) investigation of the effects of radiation and other weapons-associated trauma on the animals; and (3) studies of measures to prevent, ameliorate, and treat injury.

These experiments were carefully planned and were conducted to get the maximum amount of useful information from them. Eight thousand animals, ranging from mice to dogs to even camels, were used; their distances from the blast, orientation to the blast, and placement in vehicles or military or civilian structures (over 200 such items were used) were well organized beforehand. Procedures for recovering the animals, including adequate staffing, transport, and laboratory facilities, were also established in advance. Data processing was then thoroughly conducted. As a result, several recommendations were developed on how to treat acute radiation-induced disease with and without combined injuries. A clearer understanding was also developed of the dangers of fallout in terms of both inhalation injuries and entry into the food chain (specifically in milk) and eventual ingestion. Although these principles have never been put into practice in a weapons-related situation, they were valuable in advancing scientific and medical knowledge and allowed physicians to better treat persons injured at Chernobyl and in other accidents.

The medical principles learned from these experiments would benefit only a relatively small portion of the casualties in the event of a wartime exchange of nuclear weapons. However, these principles, with the additional lessons learned by the worldwide medical community from the accidents at Chernobyl, Goiânia (Brazil), and other less catastrophic incidents would be of value if

another reactor accident occurred or a terrorist used a small nuclear weapon or improvised nuclear device. The discoveries from these animal experiments are of historical value in any case, and many of the principles and recommendations developed are still in use in modern radiation medicine.

The Defense Threat Reduction Agency (DTRA) provided funding and contractual management support for this report. DTRA is now publishing this report to disseminate these very important data and their analysis for critical review and evaluation. It should be stressed that this document, including the collection, presentation, and conclusions derived from the data presented, is entirely the work of the authors. Aside from grammatical correction, occasional clarification of scientific terminology, and changing of radiation units to more current units, DTRA did not collaborate in this report. We were especially careful to ensure that any editorial changes made did not alter the scientific content but only its clarity, format and presentation. The opinions expressed in this document are therefore entirely those of the authors and do not represent those of DTRA, the United States Department of Defense, or the United States Government.

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ABSTRACT

This two-part document, originally titled "Historical Analysis of Atmospheric Nuclear Explosion Effects on Experimental Animals during Early Nuclear Tests, Part One and Part Two" (V.A. Logachev and L.A. Mikhalikhina, Sarov; Moscow, 1996), describes the effects on animal models of atmospheric nuclear weapons tests performed by the Soviet Union at the Semipalatinsk Test Site. Part 1 describes the air blast and thermal radiation effects. Part 2 covers the effects of primary (prompt) radiation and secondary (fallout) radiation on the test subjects. It also covers combined radiation injuries, defined as a combination of radiation and non-radiation injuries. Several different animal species were used. Animals were emplaced at varying distances from the explosion's epicenter, and in a variety of terrain configurations (open ground, trenches oriented parallel and perpendicular to the blast, etc.) The protective effects of shielding from different military vehicles and buildings were also studied. The types, degrees of severity, and clinical course of illness from the injuries produced were carefully studied in order to better understand the pathogenic mechanisms of injury and the likelihood of efficacy of proposed treatment measures. This document also covers special organ effects such as flash blindness and retinal burns. Even though these data are now over fifty years old, many of the conclusions derived from their analysis are useful today in terms of protecting humans from injury and affording good medical treatment of injuries incurred from detonation of a nuclear weapon or device.

CONVERSION TABLE

Conversion Factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY ⟶ BY ⟶ TO GET
TO GET ⟵ BY ⟵ DIVIDE

angstrom	1.000 000 x E -10	meters (m)
atmosphere (normal)	1.013 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E +2	kilo pascal (kPa)
barn	1.000 000 x E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 x E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 x E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 x E +1	*giga bacquerel (GBq)
degree (angle)	1.745 329 x E -2	radian (rad)
degree Fahrenheit	$t_k = (t^\circ f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 x E -19	joule (J)
erg	1.000 000 x E -7	joule (J)
erg/second	1.000 000 x E -7	watt (W)
foot	3.048 000 x E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E -3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E +9	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E -6	meter (m)
mil	2.540 000 x E -5	meter (m)
mile (international)	1.609 344 x E +3	meter (m)
ounce	2.834 952 x E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E -1	newton-meter (N-m)
pound-force/inch	1.751 268 x E +2	newton/meter (N/m)
pound-force/foot^2	4.788 026 x E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 x E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E -2	kilogram-meter^2 (kg-m^2)
pound-mass/foot^3	1.601 846 x E +1	kilogram-meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 x E -2	**Gray (Gy)
roentgen	2.579 760 x E -4	coulomb/kilogram (C/kg)
shake	1.000 000 x E -8	second (s)
slug	1.459 390 x E +1	kilogram (kg)
torr (mm Hg, 0^0 C)	1.333 22 x E -1	kilo pascal (kPa)

*The bacquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (GY) is the SI unit of absorbed radiation.

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PART 1

ORGANIZATION OF MEDICAL AND BIOLOGICAL STUDIES: PRINCIPAL TASKS AND APPROACHES TO THEIR SOLUTIONS

Introduction

The first part of this document considers the specific effects of blast and thermal radiation resulting from a nuclear explosion. It is comprised of three chapters.

The first chapter (p. 8) contains the organizational issues for the medical and biological studies that represent a part of the integrated program of nuclear testing. It gives a description of the research objectives supporting organizational structures and the ways to achieve these objectives.

The second chapter (p. 13) is mainly devoted to the experimental data on blast effects impacting various animal species that were emplaced within the target environment at the test sites on the ground surface, in fortification structures such as residential and industrial buildings, and in various types of military vehicles and equipment.

The third chapter (p. 26) presents the research results for the effects of thermal (thermal and light) radiation of nuclear explosions. Significant interest is given to data on the thermal injury of the organs of sight.

The second part of the document examines (1) penetrating radiation (primary radiation), (2) combined radiological injuries, and (3) the use of experimental animals to study specific effects of radioactive fallout and residual radiation. It also consists of three chapters.

The first chapter (p. 46) contains a detailed description of the clinical patterns for various radiation disease levels resulting from low-, medium-, and high-yield air and ground surface explosions. In addition, generic differences in the response to ionizing radiation are considered. It is recognized that radiological sensitivity of dogs is similar to that of man for gamma-neutron radiation ("Those who live need it," *Atompressa*, No. 45 (191), December 1995). Therefore field experiments most frequently used dogs to solve medical and biological problems.

The classification and description of combined injuries (radiological-thermal and radiological-mechanical) are given in the second chapter (p. 68). This chapter also contains recommendations for the treatment of acute radiation disease (ARD) and combined injuries developed in the early 1950s during the medical and biological program.

The third chapter (p. 76) presents data obtained from experiments on the radioactive fallout from the ground-surface explosions. Greatest emphasis is given to (1) radiological skin injuries, (2) the hazard levels of inhalation, and (3) peroral penetration of radioactive materials.

Classification of Nuclear Explosions and Their Effects

Another report[1] gives a brief description of the Semipalatinsk Test Site and atmospheric nuclear

tests conducted there in 1949-1962. During 1955-1958, the three years of the most intensive tests, thermonuclear explosions produced the TNT equivalent of 5,520 kt or 84% of the total energy released from all atmospheric tests at the Semipalatinsk Test Site (6,600 kt).

It should be noted that studies of nuclear explosion impact on experimental animals were performed since the very beginning of the Soviet nuclear weapons program. The most extensive studies were carried out during atmospheric nuclear tests on November 6, 1955 and November 22, 1955.

The entire Soviet nuclear weapons program was greatly influenced by the test of November 22, 1955, which in its preparatory and shot phases combined up-to-date development of a nuclear device design and an extensive medical and biological research program involving experimental animals to study the effects of nuclear explosions.

Along with the need to reach nuclear parity with the United States in the future, it was also necessary to estimate the possible consequences resulting from the large-scale use of nuclear weapons by the USA in order to develop methods for minimizing the loss of human life and economic potential and to find methods for optimum protection.[2] In these historical conditions it was important to study the effects of nuclear explosions where the role of the medical and biological programs was difficult to estimate. The problem was not only to study how the effects of a nuclear explosion effects impact military facilities during war activities but also how they impact military engineering facilities, transport and industry facilities, national logistics, and protective structures.

Studies using experimental animals during atmospheric tests were carried out on various scales to solve multiple problems in approximately 25 nuclear events that differed in yield (energy release) of nuclear devices. Since the degree and specificity of injurious effects of nuclear explosions primarily depend on the yield (energy release), the work performed and existing experimental data allowed all nuclear charges to be divided into five groups:

- superlow caliber (less than 1 kt);
- small caliber (1-10 kt);
- medium caliber (10-100 kt);
- large caliber (100-1,000 kt);
- superlarge caliber (more than 1,000 kt).

Generalization of experimental data made it obvious that the studies of injurious effects should be carried out independently for (ground) surface and atmospheric explosions by classifying these explosions in terms of the charge yield: low, medium and large.

For surface explosions, the scaled height of burst $\overline{H}$ was obtained from the formula $\overline{H} = \frac{H}{\sqrt[3]{W}} < 35\ \mathrm{m/kt^{1/3}}$, where H is the absolute height of burst in meters, W is the energy release in TNT equivalent kilotons. For atmospheric explosions the formula $\overline{H} = \frac{H}{\sqrt[3]{W}} > 35\ \mathrm{m/kt^{1/3}}$ was used.

The main nuclear explosion effects from the burst center (epicenter) impacting the animals included:

- blast;
- thermal radiation; and
- penetrating radiation.

For surface nuclear explosions, about 40% of all radionuclides resulting from the explosion fall out within the local trace of the radioactive contamination bounded by a gamma dose of 400 mSv (40 R) after complete decay of the fission products. Territory contamination from surface explosions also produces an important injurious effect; therefore studies of radiological injuries resulting from both internal and external irradiation of the animals were also performed. Special importance was given to studies of inhalation-driven penetration of particles with variable sizes both in the phase of contamination from the passing cloud tail (referred to as primary contamination of the air layer near the surface) and later, after the fallout of radioactive products from the cloud had stopped (secondary air contamination). To do this dogs were used that allowed the specialists to obtain credible data. We intend to include the analysis results of these data in the second part of the report.

The following injury levels were used in considering the effects of the blast shock wave and the thermal radiation effects.

The first level includes injuries that completely resolved. As applied to humans, this level includes the proportion of casualties that lose fighting and working capabilities for a short period after the exposure.

The second level includes injuries with a relatively good outcome. As applied to humans, this level includes casualties that lose fighting and working capabilities for a longer period of time. Lethality is possible for a small percentage of this level as the result of later illness and after-effects.

The third level includes injuries with significantly unfavorable outcomes, where lethality could reach 20-80% of the number of injured individuals in this injury level.

The injury level of nuclear explosion effects on experimental animals was determined by the distance from the burst center (epicenter) and the protection of an animal from a given effect.

Main Objectives of Animal Experiments and Approaches to Solutions

From our viewpoint it is essential to pay special attention to the purposes of nuclear atmospheric tests. A compact classification of these purposes is:

1. development and further improvement of nuclear weapons;
2. studies of effects of nuclear explosions and means of protection;
3. studies of abnormal modes that may occur during the operation of nuclear devices and specific features of accidental situations with subsequent recommendations for the elimination of consequences;

4. fundamental investigations of laws typical for nuclear explosions and methodical efforts for recording the parameters of fast processes.

The most important biological problems were solved by investigations of nuclear explosion impacts combined with fundamental research. The preparation and implementation of nuclear tests necessitated the solution of three medical-biological problems:

1. radiological safety for all test participants as well as the surrounding civilian population and prevention of economic loss (for example, damaging of the harvest in the regions neighboring the test site);
2. investigation of how ionizing radiation and other nuclear explosion effects impact living organisms;
3. efficiency studies for preventive measures and injury treatment.

Specific sub-objectives were formulated as follows:

- Accurate evaluation of values for physical parameters of nuclear explosion effects as applied to each biological point of the test field;
- Evaluation of the impact of nuclear explosion effects on animals in strict comparison with the physical parameters of nuclear explosion effects. Special attention was given to the investigations of penetrating radiation (gamma quanta, neutrons), thermal radiation, and blast effects;
- Investigations of the nature and degree of injury to the organs of sight;
- Understanding of the clinical history of traumas, contusions, and burns;
- Evaluation of possible contamination levels resulting from radioactive particles and the efficiency of veterinary treatment (decontamination) for animals;
- Determining the specificity of clinical history and early diagnosis of radiation injury results;
- Comparison and determination of relative efficiency of various preventive and treatment means for radiation injuries (radioprotectors);
- Investigations of the nature of pathologic-anatomic changes of animals affected by nuclear explosion effects;
- Reliability evaluation of various collective and individual means of protection from nuclear explosion effects;
- Understanding the role of contaminated territory in the causation of injurious effects (residual radiation);
- Probability evaluation for long-term consequences of radiation injuries.

Estimated results of the impact of nuclear explosion effects on animals served as the basis for solving subsequent medical problems relating to the least studied effect -- the impact of ionizing radiation. Diagnostic methods for identifying radiation disease and an understanding of the clinical patterns of radiation and combined injuries have to be known in order to describe the mechanisms of their evolution and to develop methods of prevention and treatment.

There were sufficient data to present test results relatively well with regard to various means of prevention of radiation disease and treatment of animals exposed to nuclear explosion effects, as well as generalized data on the injury of sight organs from nuclear explosion effects during the

day and at night. Issues related to the pathologic anatomy of radiation diseases were also considered.

The medical/biological studies involved about 8,000 experimental animals (camels, horses, pigs, sheep, dogs, rabbits, guinea pigs, white rats). The basic ways to solve medical/biological problems were by carrying out field experiments that used animals in open areas of test fields and in military and civilian protective structures. Animals were placed in more than 500 field and long-term structures, more than 200 war materiel items (tanks, armored personnel carriers, automobiles, aircrafts etc.), and residential brick and wooden houses.

The investigation of the injurious effects of nuclear explosions on organisms was an important and difficult problem both in terms of developing a methodical scientific basis for field experiments and in terms of organization; i.e., the development of basic organizational principles for medical/biological research. As stated above, experimental data were generalized separately for surface and atmospheric explosions of low-, medium-, and high-yield warheads.

CHAPTER 1

ORGANIZATIONAL PRINCIPLES AND RESEARCH IMPLEMENTATION

1.1 IMPLEMENTATION

The implementation process for each medical-biological research program during atmospheric tests was divided into three basic periods: preparation, experimentation, and data processing/generalization.

Before each nuclear test at the Semipalatinsk Test Site, i.e. in the pre-shot period, the institutions and departments involved in the research efforts performed a large amount of works to evaluate and formulate the tasks. The contents of the research programs were clarified, methods were developed, scientific and support staffs were organized, and ways and means were found for logistical support.

The preshot period usually involved the following tasks:

- Formulating instructions to define the rules for various operations and strict adherence to those rules by personnel from institutions involved in the research efforts.
- Breeding (reproduction) of small laboratory animals; procurement and placement of large animals in vivariums.
- Veterinary examination of experimental animals.
- Marking animals according to type and number of biological points (stations). The biological point of the target environment indicated a specially selected group of animals, often consisting of various animal species that were to be placed at a given time and point of the test field.
- Manufacturing tools for emplacement of the animals during transport and at the biological points in the test field.
- Preparation of sites for laboratory and clinical examination of the animals.
- Serial clinical and laboratory examination of the experimental animals was planned in order to obtain credible data on the initial state of the animal and subsequent status.
- Preliminary preparation of sites for animals before and at the test field.
- Training of animals intended for emplacement in special chambers, cages, etc. and estimating their reflexes.
- Rehearsals.

The experimentation period usually lasted for about three days. This crucial period usually included the following tasks accomplished in accordance with the specific contents of the medical-biological program:

- Emplacement of the animals and control devices at the test field at the specified biological points and times.
- Examination of the biological points after the shot and generation of brief documents characterizing the state of the animals, equipment and control devices.

- Removal of animals from the test field to a specially equipped veterinary treatment station and transportation to the clinics of the biological sector of the scientific department at the test site.
- Collection of animal carcasses, veterinary treatment and transportation for pathologic and anatomic studies.
- Beginning clinical and laboratory studies and treatment of animals with respect to special or partial research tasks (often accomplished with methods used for the first time).
- Analysis of dosimetry data for each biological point and comparison of these data with the results of clinical and laboratory examination.
- Photographing (documenting) injured animals at the biological points and in clinic together with the pathologic and anatomic specimens.
- Formulation of a brief expedited report with the early research data and specification of general ideas about this medical-biological experiment.

In the final period data processing and generalization was performed. This lasted one or two months and was comprised of the following:

- Further clinical and laboratory examination of animals as well as other works that might have been started in the previous period.
- Processing, analyzing, and generating data on the animals' examinations.
- Preparation of the final report in accordance with the requirements of the medical-biological research program for the specific test.

Attention should be given to the important fact that the selection of animals and their examinations prior to and after the experiment followed an integrated scientifically motivated program including the following:

- General data for the animals (type, race, hair color, age, weight) and assigning a unique number.
- General state of the animal (fatness, behavior in cage, including during operations with special equipment).
- State of the:
  - Bones,
  - Skin, hair, edema, hemorrhage, damage to skin integrity,
  - Visible mucous membranes,
  - Nose and nares, upper respiratory tract, and lower respiratory tract (frequency, depth, and type of breathing) with auscultation and percussion,
  - Cardiovascular system (pulse, sounds) via auscultation and palpation,
  - Alimentary canal (appetite, thirst, sialorrhea, vomiting, excrement type) including appearance of the throat and palpation of the abdomen,
  - Urogenital system and type of urine,
  - Nervous system.

The work to be done within the medical/biological program of nuclear tests shows the complexity of the tasks and the commensurate amount of labor required.
For partial or special research tasks, animals were examined within special programs using methods described in the medical/biological section of this report.

Special attention was given to the investigation and treatment of animal injuries resulting from penetrating radiation (primary radiation of nuclear explosions) and of combined injuries. Also important were the studies of radiological sensitivity, initial reactivity of the animal, and modification of radiological sensitivity of various radioprotectors and their combinations with each other and with drugs. It must also be stated that the implementation of the medical-biological program was also pursued after the atmospheric nuclear tests stopped; i.e., during the period of underground tunnel and borehole explosions. In these experiments, gamma-quanta and neutrons were emitted via special channels, and the animals were placed at different distances in both the direct beam of radiation and the scattered radiation.

The entire medical/biological research program during the nuclear events was possible only when the appropriate scientific divisions were integrated into a single organizational structure.

1.2 ORGANIZATIONAL STRUCTURES SUPPORTING THE RESEARCH

For investigating the effects of ionizing radiation on organisms and developing a means of protection, the Biological Physics Institute was founded under the Soviet Academy of Sciences (now the State Scientific Center of the Russian Federation – the Institute of Biophysics.) At different times it was headed by Academicians G.M. Frank, A.V. Lebedinsky, and P.D. Gorizontov.[4,5] Since 1968 the Institute has been headed by L.A. Ilyin, Academician of the Russian Academy of Medicine. The principal activity is still fundamental research for radiological medicine, human radiological biology, and the ecological-hygienic basis of radiation protection.

A Medical-Biological Department was established in 1948-1949 at the Semipalatinsk Test Site and contained nine divisions: hematology, biological physics, pathomorphology, biochemistry, dosimetry, biology, clinical, pharmacology, and X-ray. An additional division of experimental therapy was created before the date of the first Soviet nuclear test on August 29, 1949.

After the Medical-Biological Department was converted to a biological sector in 1958, departments were founded for the investigation of the effects of shock wave, penetrating radiation, hygiene and toxicology. Divisions of pathological anatomy, laboratory, vivarium and pharmacy were also established.

During the period of nuclear testing the staff of the sector was comprised of several hundreds persons including some employees assigned from other institutions.

It should be noted that the Ministry of Health was responsible for the radiological safety and public health protection of individuals residing near the test site. The Ministry of Health was also responsible for the evaluation of medical-biological consequences of nuclear weapons.

The studies used many animals of different species primarily because of the need to use an appropriate animal species to solve various medical-biological problems, and secondly, by the need to extrapolate data obtained from animals to humans. [6] About 8,000 animals were used in

1949-1957, the period of the most intensive medical-biological studies. Data on the number of animals are provided in Table 1.

Table 1. The number of animals used for the medical-biological experiments in 1948-1959.

Animal species	Relative quantity, %
Sheep	40
Horses	1
Cattle	1
Camels	0.5
Pigs	0.5
Dogs	11
Rabbits	6
Guinea Pigs	5
White Rats	35

Note: Laboratory mice are not included. Several thousands were used.

The data from Table 1 indicate that the basic group included sheep, dogs, and rabbits, if the contribution of white rats is ignored.

In addition to the quantity of animals used, the professional preparation of each investigation was very important for the successful solution of tasks. The former leader of the 3rd Chief Directorate of the Ministry of Health, A.I. Burnasian, paid a great deal of attention to the skill of the staff.

Prior to the field operations the employees of the biological sector were trained in terms of general and specific knowledge in various research and clinic institutions, such as the Biological Physics Institute, All-Union Pathology Institute, Food Institute, Burdenko Military Hospital, Military Academy of Medicine, Military Veterinary Academy, etc.

The usual number of personnel in the medical-biological department was not great; however it was sufficient for long-term examination of animals retained after the shot. For the experimentation period the staff was augmented by assigned specialists. The teams of the medical-biological department included highly skilled specialists. The divisions were usually headed by Candidates of Medicine or Biology.

The employees of the medical-biological department developed the methods for fixation of animals at the test field relative to specific emplacement conditions for the experimental animals.

Chains were used for horses, cattle and camels on the ground surface with chains connected to poles. For sheep and dogs, there were specially developed tarpaulin breast-bands impregnated with liquid glass to avoid ignition. They were fixed with chains connected to rods buried into the soil. Pigs and small animals were emplaced in metal net cages. The cages were fixed to the soil by rods.

For engineering structure and war material items, the fixing technology remained the same as for the ground surface except that the chains were attached to the protruding elements of the structures or war material rather than to buried rods.

The animals were transported in trucks using field fixing tools attached to special supports.

A significant achievement in the preparation and implementation of medical-biological investigations was the development of methods and devices for remote recording of physiological functions of the animal experiencing the nuclear explosion effects.

1.3 CHARACTERIZATION OF ANIMAL INJURIES FROM THE AIR SHOCK WAVE AND THERMAL RADIATION

During atmospheric nuclear testing the experimental animals could be affected by the airblast, thermal radiation, penetrating radiation (primary radiation) and territory contamination (residual radiation). The nature and degree of injuries greatly depended on the distance from the epicenter, explosion yield, structure features of shelters (engineering structures, war material etc.), landscape, and weather conditions. In each specific case near the epicenter of the test field, injuries of the experimental animals resulted either from one of the above factors or their combination. The impacts of other, more exotic effects of a nuclear explosion, such as electromagnetic pulse (EMP), gas flow, etc. were not studied during the period of interest.

The injuries of experimental animals from the airblast were considered as contusion of various levels:

- light (1st level);
- medium (2nd level);
- severe (3rd level);
- immediate death ("lightning rate" contusion).

Light injuries included those where the clinic findings were weakly expressed. The first hours demonstrated only moderate excitation with global tremor and at times stereotypical movement of paws and head. Depression, decreased appetite, and impairment of eye-heart reflexes were observed. Emphysema of the lungs, enlargement of retinal veins, and edema of the optic nerve disc confirmed the diagnosis of a light contusion. Medium level injuries include those where the animals, during the first 1-2 weeks, demonstrated low reactivity, decreased tendon and pupillary reflexes, bad hearing or disappearance of hearing, ataxia, low appetite, somewhat increased pulse rate, moderate decrease in blood pressure, and bleeding at the nose and mouth. During the first several days neutrophil leukocytosis was observed.

Severe injuries include those where, during the first hours after the shot, the animals demonstrated a global "heavy" state: acute depression, adynamia, no response to external irritants, complete rejection of forage, occasional vomiting, liquid diarrhea, well-pronounced neurological symptoms, decreased blood pressure, changes in cardiovascular system functions in the form of bradycardia, and changes in the peripheral blood (neutrophil leukocytosis with relative lymphopenia). The "lightning rate" contusion (immediate death) includes those injuries that resulted in lethality either at the time of shock wave impact or in a few minutes after the shock arrival. For estimating the injury level resulting from thermal radiation the following classification was proposed for skin burn: hair singeing, and first, second, third, and fourth degree burn levels. A detailed description for each burn level and possible injuries of sight

organs are provided under the heading "Thermal Injuries of Visual Organs."

Generalization of the data obtained from the experiments involving animals provided a well-posed approach to editing several manuals for evaluating the Army's fighting efficiency and operational capabilities of its rear facilities and for preparing material to develop a coordinate injury law for nuclear weapons. [8, 9] This law is based on the dependence between the minimum level of injury sustained by a biological object and the coordinates of this object relative to the hypocenter of an explosion with a given yield. The shock wave impact upon the biological object was crucial in some cases.

CHAPTER 2
GENERALIZED RESULTS OF EXPERIMENTAL DATA ON INJURIOUS EFFECTS OF THE AIR SHOCK WAVE ON ANIMALS

2.1 FEATURES OF THE AIR SHOCK WAVE EFFECT

Currently it is well known that an air shock wave (ASW) is the principal carrier of destructive mechanical energy from a nuclear explosion. Due to the increase in duration of effect and the higher velocity head pressure of the leading edge of the shock wave (primary blast wave front) as compared to a shock wave from ordinary weapon explosion, the ASW from a nuclear explosion is capable of damage at lower values of overpressure, which is at considerably larger distances from the explosion center (epicenter). Lethal damages of cattle located on an open ground from direct impact of a shock wave from ordinary TNT charge explosions were observed at an overpressure (ΔP_f) on the order of 1-2 MPa (10-20 kgf/cm^2) and lower.

The ASW effect on the body surface of an unshielded animal facing a direct nuclear explosion was comprised of the velocity head pressure or blast wave front (ΔP_v) and the overpressure from the shock wave front. Also of great importance was the compression phase action time (τ_+) of the ASW. With increasing compression phase action time ASW damage degree also increased. Increase in the compression phase action time took place with increasing nuclear explosion yield. For example, at an explosion of 20 kt of TNT equivalent the compression phase action time at average distances was 0.6 s, while it was 3 s from a 1 Mt yield.

In addition to the direct effect ASW also had a pronounced cast effect (i.e., displacement of the animal, or translational injury) on animals by virtue of the effect of the moving blast wave front. The cast effect is one of the distinguishing features of nuclear explosion ASW injurious effects. Damage from the ASW cast effect depended on the distance an animal's body was thrown, the velocity upon ground impact, the height from which it fell, and a set of other coincidental factors: impact localization and collision surface properties.

A nuclear explosion ASW can scatter debris and fragments of destroyed entities at a high speed and for considerable distances. Such debris and fragments caused severe trauma and wounds for the experimental animals. The character and severity of animal injuries depended on the shock localization rate, mass, density, shape and other properties of such flying debris and fragments.

The experiments made allowed us to find that the damage from a nuclear explosion ASW can be subdivided into three classes: primary, secondary and tertiary.

Primary damage occurs from the direct ASW effect (the overpressure at the shock wave front), secondary damage (wounds, contusions) from the traumatizing effect of flying debris and fragments, and tertiary damage due to the impact of an animal on the ground and other objects when its body was thrown by the blast wave front.
It is also important to note that the nuclear explosion and its ASW were attended with infrasound and sound oscillations (up to 150-170 db) which caused acute acoustic trauma of the animals with injury of the spiral (Corti's) organ. The primary damage with the ASW involved damage of

the auditory organs of the animals, non-penetrating trauma to the brain and spinal cord, and the thoracic and abdominal organs. In the brain small vessels were primarily injured, while in the spinal cord the extrapyramidal system roots and formations were most significantly involved. These structural damages were, as a rule, complicated by local circulation disorders, cerebrospinal fluid generation and circulation, brain substance swelling and edema which, in its turn, promoted occurrence of degenerative changes in nerve fibers, cells, and glia.

Hemorrhages in the lungs were also observed; these were due to rupture of interalveolar membranes, capillaries and vessels. The degree and character of the lung hemorrhages varied from small extravasation interleaving with emphysema to voluminous merging foci covering a lung lobe and even the whole lung. A most characteristic localization of such hemorrhages was the rib lung surface. Hemorrhages in the small intestine mesentery and peritoneal tissues, as well as ruptures of the mucous and muscle stomach membranes in the small and large intestines, were often observed. The animals which suffered from indirect trauma (secondary and tertiary damages) often exhibited wounds of soft tissues, closed and open bone fractures, contusions, skull and brain damage, as well as slight tears and ruptures of the internal organs attended by acute loss of blood and a shock.

2.2 INJURY LEVEL OF ANIMALS FOR VARIOUS EMPLACEMENT CONDITIONS AT THE TEST FIELD

The nuclear weapons tests allowed us to conclude that, for explosions differing in yield, the injury pattern of animals due to the ASW does not differ from that resulting from conventional bombs and projectiles containing chemical explosives. The injury level depended on the overpressure from the shock front at the corresponding distance from the epicenter, velocity of the shock wave front, and the duration of the compression phase. [10,11]

Injuries resulting directly from the ASW from ground explosions of low-yield nuclear devices within 400-450 m were very severe and led to lethality of the unprotected animals that were emplaced on the ground surface.

The minimum shock front overpressure was 12-120 MPa (1.2-12.0 kgf/cm^2). Medium scale injuries were observed at the 700-750 m range, and light injuries occurred at 1,000-1,100 m from the epicenter. The blast wave front overpressure could vary from four to 15 MPa (0.4 to 0.15 kgf/cm$^{2)}$.

For ground surface explosions of medium yield devices, the lethality zone was about 1,000 m. Shock wave front overpressure required for this effect were 8-10 MPa (0.8-1.0 kgf/cm$^{2)}$. The area of the severe, medium, and light injury zones increased considerably.

Only one ground surface burst of a high-yield device was produced. It was conducted on August 12, 1953 with a yield of 400 kt [12]. After this shot, lethality of animals on the ground surface was observed within a radius of 2,000 m. The boundary of the light injury zone was about 3,200 m from the epicenter.

The effects of low-, medium-, and high-yield explosions on animals emplaced on the ground surface at various distances from the burst center are given in Table 2. Of the 480 animals, 104 were killed, and 109 animals experienced injuries of various levels.

Injury data for animals placed in open trenches, closed engineering structures, and war materiel units are presented in Tables 3 through 5.

Table 2: Blast effects from ground surface explosions of various yields on experimental animals on the ground surface.

Distance, m	Low Yield[1]							Medium Yield							High Yield						
	ΔP_f[2] MPa	Number of Animals						ΔP_f, MPa	Number of Animals						ΔP_f, MPa	Number of Animals					
		Total	Killed	Injury level[3]			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
75-400	30-10.7	47	43	4	0	0		-	-	-	-	-	-		-	-	-	-	-	-	
440-700	12-7	52	9	13	20	6		30-19	12	12	0	0	0		-	-	-	-	-	-	
730-1000	6-2.8	35	0	0	4	12		17-9.4	39	17	3	4	0		110-40	6	6	0	0	0	
1050-1800	3-1.8	45	0	0	0	11		8-2.5	61	1	8	0	1		25-14	13	13	0	0	0	
1900-4000	-	-	-	-	-	-		2-0.8	115	0	0	0	10		12-03.8	27	3	1	8	4	
4100-8000	-	-	-	-	-	-		0.5-0.3	22	0	0	0	0		3-1.6	6	0	0	0	0	
Total		179	52	17	24	29	57		249	30	11	4	11	193		52	22	1	8	4	17

Notes:

[1] *The TNT equivalent was 1-10 kt for low-yield devices, 10-100 kt for medium-yield devices, and 100-1,000 kt for high-yield devices.*
[2] *ΔP_f= Shock wave front overpressure, MPa (1 MPa = 102,000 kgf/cm^2).*
[3] *Level I = light injuries, level II = medium injuries, level III = severe injuries.*

Table 3: Blast effects from ground surface explosions of various yields on experimental animals in open trenches.

Distance, m	Low Yield							Medium Yield							High Yield						
	ΔP_f MPa	Number of Animals						ΔP_f MPa	Number of Animals						ΔP_f MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
75-400	30-17	30	21	4	3	1		>30	10	10	0	0	0		-	-	-	-	-	-	
440-700	12-7	24	0	6	8	4		30-19	10	8	0	0	0		-	-	-	-	-	-	
730-1000	6-2.8	28	0	0	4	9		17-9.4	206	6	0	2	0		110-40	12	12	0	0	0	
1050-1800	3-1.8	-	-	-	-	-		8-2.5	134	2	0	0	0		25-14	18	5	1	8	0	
1900-4000	-	-	-	-	-	-		2-0.8	4	0	0	0	0		12-3.8	12	2	0	0	0	
4100-8000	-	-	-	-	-	-		0.5-0.3	-	-	-	-	-		3-1.6	-	-	-	-	-	
Total		82	21	10	15	14	22		364	26	0	2	0	336		42	19	1	8	0	14

Table 4: Blast effects from ground surface explosions of various yields on experimental animals in closed engineering structures.

Distance, m	Low Yield							Medium Yield							High Yield						
	ΔP_f MPa	Number of Animals						ΔP_f MPa	Number of Animals						ΔP_f MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
75-400	30-10.7	26	7	0	0	0		>30	64	51	0	0	0		-	-	-	-	-	-	
440-700	12-7	20	0	0	1	0		30-19	137	4	1	0	0		>110	23	18	2	0	0	
730-1000	6-2.8	18	0	0	0	0		17-9.4	124	49	0	0	0		110-40	23	13	9	0	0	
1050-1800	3-1.8	-	-	-	-	-		8-2.5	127	23	0	0	0		25-14	23	9	2	0	0	
1900-4000	-	-	-	-	-	-		2-0.8	26	0	0	0	0		12-3.8	26	12	-	-	-	
4100-8000	-	-	-	-	-	-		0.5-0.3	-	-	-	-	-		3-1.6	6	0	0	0	0	
Total		64	7	0	1	0	56		478	127	1	0	0	350		101	52	13	0	0	36

Note:

The engineering structures were represented by military wood and soil shelters, dugouts, and reinforced concrete blocks for firing units.

Table 5: Blast effects from ground surface explosions of various yields on experimental animals in war materiel units.

Distance, m	Low Yield							Medium Yield							High Yield						
	ΔP_f MPa	Number of Animals						ΔP_f, MPa	Number of Animals						ΔP_f, MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
75-400	30-17	19	13	3	3	0		>30	17	9	0	0	0		-	-	-	-	-	-	
440-700	12-7	15	0	5	0	2		30-19	19	7	2	0	0		-	-	-	-	-	-	
730-1000	6-2.8	8	0	0	0	1		17-9.4	36	1	7	0	0		-	-	-	-	-	-	
1050-1800	3-1.8	-	-	-	-	-		8-2.5	37	0	0	4	2		25-14	10	5	2	0	0	
1900-4000	-	-	-	-	-	-		2-0.8	24	0	0	0	0		12-3.8	-	-	-	-	-	
4100-8000	-	-	-	-	-	-		0.5-0.3	-	-	-	-	-		-	-	-	-	-	-	
Total		42	13	8	3	3	15		133	17	9	4	2	101		10	5	2	0	0	3

Note:

The war materiel was represented by tanks, self-propelled artillery systems, and closed armored personnel carriers.

The animals in engineering structures or in war materiel units buried into soil experienced a smaller effect from the shock wave front because the latter did not encounter barriers; the overpressure therefore did not increase because of the lack of shock wave reflection.

The studies also revealed a specific property of the ASW; i.e., its ability to flow into (penetrate) the engineering structures and "closed" war materiel units through the slots, air inlets etc., thus producing damage and injuring the animals. When the ASW penetrated the structures or war materiel units, the overpressure increased rapidly, causing injury and death to the animals.

The closed engineering structures were represented by shelters, reinforced concrete chambers, and blocks of long-term fortifications, armored hoods, light and heavy shelters, subway tunnel segments, etc. To study the protective properties of war materiel, the animals were placed in self-propelled artillery systems (ISU-152, SU-100, SU-122), armored carriers, tanks (T-34, T-54, IS-3), and aircraft (IL-10, La-9, Pe-9, TU-2).

The specific properties of the shock front waves impacting the animals from atmospheric explosions of various yields are given in Tables 6 through 9.

Table 6: Blast effects from atmospheric explosions of various yields on experimental animals on the ground surface.

Distance from the epicenter, m	Low Yield (W<10 kt; H=55-265 m)							Medium Yield (W=31-62 kt; H=270-1,050 m)							High Yield (W=200-1,800 kt; H=1,000-1,550 m)						
	ΔP_f MPa	Number of Animals						ΔP_f, MPa	Number of Animals						ΔP_f, MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
50-400	10-4	74	22	4	8	7		30-11	27	25	2	0	0		-	-	-	-	-	-	
420-700	5-2	71	1	4	13	5		10-8	29	25	0	4	0		-	-	-	-	-	-	
700-1000	3-1.7	31	0	2	2	0		8-6	38	30	4	4	0		-	-	-	-	-	-	
1000-1800	1.5-1	38	0	0	0	2		7-3	99	19	22	37	17		15-5.5	8	5	1	0	0	
1800-4000	<1	4	0	0	0	0		4-1	102	0	2	29	36		12.5-3.5	51	17	17	9	2	
4000-8000	-	-	-	-	-	-		1-0.5	22	0	0	0	3		6.5-2	65	1	21	16	8	
8000-10000	-	-	-	-	-	-		-	-	-	-	-	-		3-1	41	0	0	0	0	
10600-20000	-	-	-	-	-	-		-	-	-	-	-	-		2.5-1	21	0	0	0	0	
Total		218	23	10	23	14	148		317	99	30	74	56	58		186	23	39	25	10	89

Table 7: Blast effects from atmospheric explosions of various yields on experimental animals placed in open trenches.

Distance from the epicenter, m	Low Yield (W<10 kt; H=55-265 m)							Medium Yield (W=31-62 kt; H=270-1,050 m)							High Yield (W=200-1,800 kt; H=1,000-1,550 m)						
	ΔP_f MPa	Number of Animals						ΔP_f, MPa	Number of Animals						ΔP_f, MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
50-400	10-4	42	8	9	7	12		30-11	15	12	3	0	0		-	-	-	-	-	-	
420-700	5-2	33	0	3	0	2		10-8	14	3	3	0	2		>25	6	6	0	0	0	
700-1000	3-1	37	0	0	0	0		8-6	20	2	1	4	7		>15	6	6	0	0	0	
1000-1800	<1	22	0	0	0	0		7-3	20	0	0	0	0		15-5.5	34	18	8	0	0	
1800-4000	-	-	-	-	-	-		4-1	8	0	0	0	0		12.5-3.5	24	4	6	0	0	
4000-8000	-	-	-	-	-	-		-	-	-	-	-	-		6.5-2	12	0	0	0	0	
8000-10000	-	-	-	-	-	-		-	-	-	-	-	-		3-1	6	0	0	0	0	
10000-20000	-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-	
Total		134	8	12	7	14	93		77	17	7	4	9	40		88	34	14	0	0	40

Table 8: Blast effects from atmospheric explosions of various yields on experimental animals placed in closed engineering structures.

Distance from the epicenter, m	Low Yield (W<10 kt; H=55-265 m)							Medium Yield (W=31-62 kt; H=270-1,050 m)							High Yield						
	ΔP_f MPa	Number of Animals						ΔP_f, MPa	Number of Animals						ΔP_f, MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
50-400	10-4	20	2	5	0	0		30-11	14	4	0	0	0		-	16	2	4	3	1	
400-700	5-2	36	0	0	0	0		10-8	16	0	0	0	0		>25	24	4	2	2	2	
700-1000	3-1	32	0	0	0	0		8-6	18	3	0	0	0		>15	16	-	-	-	-	
1000-1800	<1	36	1	1	0	0		7-3	34	2	0	0	0		15-5.5	12	2	3	-	1	
1800-4000	<1	4	0	0	0	0		4-1	22	1	0	0	0		12.5-3.5	20	2	0	0	0	
4000-8000	-	-	-	-	-	-		<1	2	0	0	0	0		6.5-2	7	0	0	0	0	
Total		128	3	6	0	0	119		106	10	0	0	0	96		95	10	9	5	4	67

Table 9: Blast effects from atmospheric explosions of various yields on experimental animals placed in war materiel units.

Distance from the epicenter, m	Low Yield (W<10 kt; H=55-265 m)							Medium Yield (W=31-62 kt; H=270-1,050 m)							High Yield (W=200-1,800 kt; H=1,000-1,550 m)						
	ΔP_f MPa	Number of Animals						ΔP_f, MPa	Number of Animals						ΔP_f, MPa	Number of Animals					
		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured		Total	Killed	Injury level			Un-injured
				III	II	I					III	II	I					III	II	I	
50-400	10-4	57	13	14	2	1		30-11	2	2	0	0	0		-	-	-	-	-	-	
400-700	5-2	51	0	2	1	0		10-8	14	0	4	1	7		-	-	-	-	-	-	
700-1000	3-1.7	10	0	0	0	0		8-6	26	4	2	0	0		-	-	-	-	-	-	
1000-1800	<1	10	0	0	0	0		7-3	18	1	0	0	0		15-5.5	38	0	0	0	0	
1800-4000	-	-	-	-	-	-		4-1	15	0	0	0	0		12.5-3.5	34	0	0	0	0	
4000-8000	-	-	-	-	-	-		-	-	-	-	-	3		6.5-2	30	0	0	0	0	
Total		128	13	16	3	1	95		77	7	6	1	7	56		102	0	0	0	0	0

Comparison of data in Tables 2 through 9 allows one to note that it is impossible to accurately evaluate how the TNT equivalent influences the shock wave front overpressure leading to injuries of certain levels, although there is a general trend toward reduction of the overpressure ΔP_f required for certain injury levels as the explosion yield increases.

2.3 DISCUSSION OF RESEARCH RESULTS

Analysis of the effects of ASW from air and surface nuclear explosions of various yields show that most significant injuries are at the severe and medium levels. Light injuries are identified with less reliability.

Almost all medical-biological investigations to study the injurious effects of atmospheric nuclear explosions were performed at the Semipalatinsk Test Site from 1949 to 1957. From March 31 to September 30 of 1958 the USSR declared a unilateral nuclear testing moratorium. All in all, during the nine years of Semipalatinsk Test Site activities from1949 through 1957, 48 nuclear tests were conducted. [13] In more than 50% of the nuclear tests medical -biological experiments were performed, using almost 8,000 animals of various types (see Table 1). The experimental animals were located freely on the ground, in 500 field and long-term structures, in more than 200 pieces of military equipment, and in dwellings and production buildings for various purposes.

Data derived from the experiments allowed assessment of the shielding properties of engineering structures and military equipment that were intended to secure protection against the various injurious effects of nuclear explosions. This analysis also considered earlier concepts of the injurious effects of nuclear explosions on animals and proposed methods for predicting various types of nuclear weapons injuries. [14, 15] Principles were also developed for identifying and organizing therapeutic measures at the stages of medical evaluation of casualties from the injurious effects of ASW and other nuclear explosion injuries. [8, 9, 16]

The results of the medical and biological studies using experimental animals confirm the fact that air shock wave injuries should be considered as contusions of various degrees.

Light contusions included contusion types with weakly expressed clinical disorders. During the early hours after the explosion only moderate excitation with general tremor were noted. Later on depression and reduced appetite were observed.

Medium (degree II) contusions included those for which considerable suppression, reduced tendon and papillary reflexes, reduced appetite, and reduced or complete absence of hearing were noted.

Results of analysis of the experimental data showed that for most dogs (18 of 20) subjected to a shock front wave effect of 2.8-4.6 MPa (0.28-0.47 kgf/cm^2) overpressure at a compression phase duration of 0.7-0.76 seconds, eardrum ruptures occurred.

With a shock wave front overpressure of 1.4-1.8 MPa (0.14-0.18 kgf/cm^2) and duration of

0.83-0.86 seconds eardrum ruptures were observed in about half of the cases (9 of 20). At an overpressure of 0.8 MPA (0.08 kgf/cm^2) and duration of 1 second no animal eardrum ruptures were noted at all.

Hearing reduction was recorded usually only in animals having eardrum damage. However, for some animals hearing was reduced even in the absence of visible eardrum damage. For most animals hearing recovery was observed 7-10 days after the injury.

Thus, based on experimental data analysis results, it can be inferred that at nuclear explosions in the atmosphere, a shock wave front of overpressure equal to or more than 4 MPa (0.4 kgf/cm^2) should be considered as dangerous for auditory organs.

The main symptoms of an extremely severe contusion (degree IV injury) were sharp depression, adynamia, absence of response to external irritants, and complete refusal of food. Multiple and, especially, combined injuries (injuries of internal organs combined with cranium trauma and bone fractures) were highly lethal despite subsequent therapy.

With atmospheric nuclear explosions degree II and III contusions occurred at shock wave front overpressure on the order of 3-3.5 MPa (0.35-0.30 kgf/cm^2). With surface explosions shock wave propagation abnormalities were weakly expressed, the kinetic energy front was also lower and, therefore, corresponding degrees of animal injury were observed at somewhat higher overpressures in the shock wave front. As already mentioned above, in addition to overpressure and air movement velocity, the duration of the ASW played a great role in determining its injurious effects.

The authors account for some of the discord in the experimental data presented in Tables 2 through 9 by imperfectness of diagnosis of contusion severity, the combined character of injuries for most animals put on the test fields, and other reasons. One of the causes for animal death was suffocation due to complete or partial crumbling of trenches that were constructed without slope revetment. In these cases the respiratory tracts of the animals were sometimes filled with soil. Animals fixed with fastening devices could not free themselves even with only a small crumbling of the soil, and were buried under ground.

It is of interest to note that during 1955-1957, when nuclear tests were distinguished with production of high-yield charge explosions, the shock wave front became the basic hazard factor. Thus, during the test of November 22, 1955, in the temporizing region located at a distance of 36 km from the explosion epicenter, a shelter collapsed on six safeguard battalion soldiers, covering them with soil. One soldier died from suffocation, while the others were contused. In the settlement of Malye Akzhary (60 km from the epicenter) a ceiling caved in, killing a girl. Forty-two persons were injured by glass fragments. This was the highest yield test conducted at the Semipalatinsk Test Site, 1.6 MT.

The next section covers the features of the injurious effects on animals from the thermal radiation from nuclear explosions.

CHAPTER 3
GENERALIZED RESULTS OF EXPERIMENTAL DATA ON INJURIOUS EFFECT OF THERMAL RADIATION ON ANIMALS

3.1 FEATURES OF THE THERMAL RADIATION EFFECT

It is necessary to describe the features of the injurious effects of thermal radiation on experimental animals to understand the physical essence of this phenomenon. Before discussing the consequences of thermal radiation, the criteria used for generalizing experimental data had to be selected. "Thermal radiation" from a nuclear explosion means electromagnetic radiation in the ultraviolet, visible and infrared spectrum regions whose source was the luminescent nuclear explosion region.

Thermal radiation energy in nuclear explosions is absorbed by surfaces of illuminated bodies that have been heated thus. The heating temperature depends on many factors and can be such that the object surface will be irradiated, melted off, or will inflame. Thermal radiation can cause burns of exposed portions of the skin of a biological object and, when it is dark at night, temporary blindness.

The luminescent region passes through three phases in its evolution: initial, first, and second.[8] Most thermal radiation energy (up to 90%) occurs during the second phase, whose duration is almost equal to the total duration of the thermal radiation emission. The duration of the luminescent region and its size increase with increasing explosion TNT equivalent (Table 10).

Table 10. Characteristics of the luminescence of a nuclear explosion by the end of the second luminescent phase.

Explosion Yield	Luminescence Duration (seconds)	Diameter (m)
Low	1-2	200-500
Medium	2-5	500-1,000
High	5-10	1,000-2,000

The main physical parameter of thermal radiation is the thermal pulse, which is thermal radiation energy quantity per unit of area of an unshielded immovable surface perpendicular to direct radiation, without taking into account reflected radiation. The thermal pulse is measured in joules per square meter (J/m^2) or in calories per square centimeter; 1 $cal/cm^2 \approx 4.2104\ J/m^2$. The former system of measurement was used during the period of atmospheric nuclear testing.

The thermal pulse decreases with the distance from the explosion center (epicenter) and depends on the explosion type and atmospheric state. For a surface explosion the fireball (luminescent region) touches the ground surface at the initial period of its evolution. Its lower

hemisphere energy is spent to heat the ground and water, and vaporize them. Thermal radiation is mainly emitted by the upper hemisphere of the fireball. In these explosions thermal radiation propagation depends on a number of factors: ground relief, absorption of some radiation portion by a dust cloud, water vapor, and carbon dioxide molecules, whose quantity is larger near the ground surface than in the upper atmospheric strata. Thus, in a surface explosion, the amount of thermal energy impinging on a biological object will be 25-50% less than in an air explosion.

The injurious effect of thermal radiation depends not only on the thermal pulse strength but also on the thermal energy fraction absorbed by each square centimeter of the surface and on the temperature the surface is heated to. In turn, the illuminated surface's temperature depends on the heat conduction and heat capacity per unit mass of the body. The higher the absorption capacity of a surface and the heat capacity per unit mass, the higher the heating temperature of the surface.

The thermal radiation effect can result in various heat injuries of the visual organs. In the experiments on animals eyelid burns were noted in almost all skin burns. It was found that the cornea and iris can be damaged only at explosions of low yield nuclear charges, since only in this case is the injurious pulse taken in before the blink reflex (0.15 sec.). The issues of visual organ injury will be discussed in a special section.

Analysis of the experimental research results showed that the main types of injuries from the nuclear explosion thermal radiation effect are heat burns of animals which can be primary, i.e. immediately from the thermal radiation effect, or secondary, i.e. from fire flame (inflammation of inflammable materials).

Reference literature published at various times in the USSR [2, 7, 8, 17, 18] distinguishes four burn degrees (Table 11). First-degree burn is a skin surface injury consisting of skin reddening only. Second-degree burn is characterized with appearance of blisters. Third-degree burn causes necrosis of the deep skin layers, and in fourth-degree skin burns, subcutaneous cellular tissue, and sometimes also deeper tissues, become charred.

Table 11. Skin burn degrees depending on thermal pulse heat density.

Burn Degree	**Heat density of pulse affecting exposed and covered portions of skin, cal/cm^2**					
	Exposed skin at explosion yield (kt)				**Skin under clothes**	
	1	10	100	1,000	Summer	Winter
First	2.4	3.2	4	4.8	6	35
Second	4	6	7	9	10	40
Third	8	9	11	12	15	50
Fourth	>8	>9	>11	>12	>15	>50

The data of Table 11 show that with decreasing explosion yield it requires less energy per area to create the same degree of skin burn. For a short duration of thermal energy impinging upon

a biological object there is less time to withdraw heat from the surface skin layer. Therefore skin surface temperature increases rapidly and, depending upon the temperature reached, the probability of a more severe burn injury increases. The severity of the thermal injury to a biological object depends not only on the burn degree, but also on the burn size.

In the animal experiments the shielding effects of various types of clothing were studied. The degree of burn by thermal radiation of animals' skin under clothing depended on the clothing type, fabric properties, color, density, thickness, etc. Free, i.e., loose clothing of white or another light color, resulted in a lesser degree of skin injury.

3.2 DEGREE OF ANIMAL INJURY FROM THERMAL RADIATION IN VARIOUS LOCATIONS

The first nuclear weapon test of August 29, 1949 showed that the clinical pictures of animal burns varied. An agreement was reached among the experts at the test site on the following burn classifications: singed hair only, first, second, third, and fourth-degree burns.

Singed hair was most frequently observed on different body areas and was extensive only in a few cases. For some animals, undamaged areas that had been covered with collars or chest bands were clearly distinguishable against the background of singed hair. In some cases, however, inflammation or smoldering of the animals' chest bands caused deep skin burns

As a rule, burns were localized on the animal's body surface facing the explosion. Muzzle and paw injuries were observed on several animals; others had injuries of different body areas. Muzzle burns were noted most frequently and occupied relatively small areas. The areas around the eye and the nasal lobes were predominantly injured. Burns in the inguinal folds region were also observed. Hence, body areas where hair cover was weakly developed were the most frequently injured.

In addition to skin burns, there were burns of the nose, throat, and laryngeal mucous membranes, which was a consequence of inhaling scorching air.

First-degree burns were detected in the form of skin erythema and limited edema at the injury site. This burn type was most clearly detected in pigs. For other animals with thick hair and pigmented skin, first degree burns were diagnosed mainly on the changes that occurred in the hairless skin areas—nasal lobes, eyelids, and inguinal regions.

In second-degree burns there was prolonged infiltration and edema at the injury site.

Third-degree burns were attended with considerable edema, tissue infiltration and scab generation at the injury site. Necrosis of separate body areas was also sometimes noted, e.g. the ear. Fourth degree burns were in the form of tissue charring. This burn type was mainly observed on corpses of animals who died from the shock wave effect at the time of the explosion and also in secondary burns of animals located in various shelters and military equipment.

The severity of an animal's clinical state from burns depended upon the degree and total surface area of the burn. A grave general state arose in animals that were severely burned. This was usually observed during day three through seven after the explosion. During that time the animals were depressed, not mobile, and responded listlessly to external irritants. In animals with second and third-degree burns their general state began to return to relatively normal around day five through ten. Dense dark-brown scabs appeared on the injury site. When the scabs appeared, further recovery of the burn surfaces was underneath the scabs. When scab generation did not occur, the infiltration and skin edema of the animals began to disappear after the fifth or sixth day. Deaths of animals with only burn injuries were very seldom observed. Death took place only when infection set in and sepsis developed.

In order to compare the clinical course of burns with the pathological changes in animals' skin during the testing of 1949, a special examination was performed on 15 pigs, one camel, one cow, and one dog. At the time of the explosion these animals were located freely on the ground at distances of 1,000, 1,250 and 1,500 m and were subjected to the ASW, thermal radiation, and penetrating radiation. A histological study of the skin of the animals which had died was performed. Skin samples were taken from the interface of the healthy and burnt surface, and were fixed in neutral 30% formalin solution. The sections were made on the freezing microtome and colored with hematoxylineozine by the van Gieson method.

Animals' skin in the burn region was of a dark-brown color, dry, and hard to the touch, testifying to second- and third-degree burns, although vesicles were not observed. All burns were of a focal character and were located on one side of the animal's body. At the histological study of the skin of animals that died on the test field, a sizeable length of the sectioned epidermis was necrotized and was found to be in the form of a structure-free border and was dark-brown in color; at times this border was completely missing. In the latter case, the surface layer was the underlying papillary corium layer. In the balsamic layer of the necrotized epidermis, unchanged cells occurred in places. Areas were observed where a burned epidermal layer was the only change. In underlying corium layers, cell wrinkling and disintegration took place, especially in the tops of the papillary layer. In addition, at the base of the skin, a plethora of small vessels and small focal hemorrhages were noted, and in one pig small point infiltrates composed of granulocyte and lymphocyte cells were located around the vessels. Hair follicle cells remained unchanged. For animals that died three to six days after the explosion, the phenomena of epidermis cell and corium surface layer necrosis and necrobiosis were detected with formation of a swelling located at the boundary of the pappilary and retina layers and were composed of local tissue cells and single granulocytes, i.e., demarcational inflammation was pronounced.

Experimental data on the consequences of the thermal radiation effect on animals located openly on the ground, in open trenches, and in closed engineering structures during various surface explosions is given in Tables 12 through 14. From the data of these tables it follows that even open type structures (trenches, dugouts, slots) protect fairly reliably against burns from thermal radiation from a nuclear explosion. Animals placed in military equipment which was not involved in fire from inflammable material inflammation were uninjured, and therefore there are no tables with this data.

Table 12. Consequences of thermal radiation effect on experimental animals on the open ground from surface nuclear explosions of various yields.

Distance from the epicenter, m	Low Yield (W<10 kt; H = 55-265 m)								Medium Yield (W = 31-62 kt; H = 270-1,050 m)								High Yield (W = 200-1,800 kt; H = 1,000-1,500 m)							
	U (cal/cm^2)[1]	Number of Animals							U (cal/cm^2)[1]	Number of Animals							U (cal/cm^2)[1]	Number of Animals						
		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured
				IV	III	II	I [2]					IV	III	II	I					IV	III	II	I	
50-400	70-49	47	43	0	0	3	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
400-700	32-9	52	9	0	4	15	11[3]	13	25	12	12	0	0	0	0	0	-	-	-	-	-	-	-	-
700-1000	13-4	35	0	0	0	18	11	6	16	39	17	0	4	12	1	5	-	6	6	0	0	0	0	0
1000-1800	8-2	45	0	0	0	1	11	33	16-8	61	1	0	2	24	25	9	-	13	13	0	0	0	0	0
1800-4000	-	-	-	-	-	-	-	-	10-2	115	0	0	1	16	98	0	26-15	27	3	0	11	13	0	0
4000-8000	-	-	-	-	-	-	-	-	2-0.6	22	0	0	0	0	0	22	10-8	6	0	0	0	4	2	0
Total		179	52	0	4	37	34	52		249	30	0	7	52	62	98		52	22	0	11	17	2	0

Notes:

[1] *U - thermal pulse, cal./cm^2. For these tables the units of measurement that were used during nuclear testing are retained.*

[2] *With first-degree skin burns scorched eyelashes and hair were also observed.*

[3] *Other animals from those which were put on the test fields and survived did not suffer burns from thermal radiation.*

Table 13. Consequences of thermal radiation effects from surface nuclear explosions of various yields on experimental animals in open trenches.

Distance from the epicenter, m	Low Yield (W<10 kt; H = 55-265 m)								Medium Yield (W = 31-62 kt; H = 270-1,050 m)								High Yield (W = 200-1,800 kt; H = 1,000-1,500 m)							
	U (cal/cm^2)[1]	Number of Animals							U (cal/cm^2)[1]	Number of Animals							U (cal/cm^2)[1]	Number of Animals						
		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-Injured[2]
				IV	III	II	I					IV	III	II	I					IV	III	II	I	
50-400	70-49	30	21	No injuries from thermal radiation				9	-	10	10	0	0	0	0	0	-	-	-	-	-	-	-	-
400-700	32-9	24	0					24	25	10	8	0	0	0	0	2	-	-	-	-	-	-	-	-
700-1000	13-4	28	0					28	16	206	6	0	2	2	7	189	-	12	12	0	0	0	0	0
1000-1800	8-2	-	-					-	16-8	134	2	No injuries from thermal radiation				132	>26	18	5	0	0	0	0	13
1800-4000	-	-	-					-	10-2	4	0					4	26-15	12	2	0	0	0	0	10
4000-8000	-	-	-					-	2-0.6	-	-					-	10-8	-	-	-	-	-	-	-
Total		82	21	0	0	0	0	61		364	26	0	2	2	7	327		42	19	0	0	0	0	23

Notes:

[1] *U - thermal pulse, cal/cm^2. For these tables the units of measurement which were used during nuclear testing are retained.*

[2] *At high-yield explosions there were no burns from thermal radiation nor hair scorching in animals in open trenches that were brought alive to the clinic from distances of 1,250-4,000 m.*

Table 14. Consequences of thermal radiation effects from surface nuclear explosions of various yields on animals in closed engineering structures.

Distance from the epicenter, m	Low Yield (W<10 kt; H = 55-265 m)								Medium Yield (W = 31-62 kt; H = 270-1,050 m)								High Yield (W = 200-1,800 kt; H = 1,000-1,500 m)							
	U (cal/cm²)[1]	Number of Animals							U (cal/cm²)[1]	Number of Animals							U (cal/cm²)[1]	Number of Animals						
		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured[2]
				IV	III	II	I					IV	III	II	I					IV	III	II	I	
50-400	70-49	26	7	No injuries from thermal radiation				19	-	-	51					13	-	-	-	-	-	-	-	-
400-700	32-9	20	0					20	25	137	4					133	-	23	18	0	4	1	0	0
700-1000	13-4	18	0					18	16	124	49					75	-	23	13	0	4	6	0	0
1000-1800	8-2	-	-					-	16-8	127	23					104	-	23	9	0	0	0	0	14
1800-4000	-	-	-					-	10-2	26	0					26	26-15	26	12	0	0	0	0	14
4000-8000	-	-	-					-	2-0.6	22	-					-	10-8	6	0	0	0	0	0	6
Total		64	7	0	0	0	0	57		478	127	0	0	0	0	351		101	52	0	8	7	0	42

Notes:

[1] *U - thermal pulse, cal/cm². For these tables the units of measurement which were used during nuclear testing are retained.*

[2] *At high-yield explosions second and third-degree burns of muzzle, ears, nasal alae, and eyelids were observed in surviving animals located in reinforced concrete structures with embrasures at a distance of 400-800 m.*

Experimental data on the consequences of the thermal radiation effect of atmospheric explosions of various yields on animals located on the open ground and in open trenches are provided in Tables 15 and 16. No injuries from thermal radiation (skin burns) were seen in animals placed in closed engineering structures and in military equipment.

Table 15. Consequences of thermal radiation effects from atmospheric nuclear explosions of various yields on animals placed on the open ground.

Distance from the epicenter, m	Low Yield (W<10 kt; H = 55-265 m)								Medium Yield (W = 31-62 kt; H = 270-1,050 m)								High Yield (W = 200-1,800 kt; H = 1,000-1,500 m)							
	U (cal/cm^2)[1]	Number of Animals							U (cal/cm^2)[1]	Number of Animals							U (cal/cm^2)[1]	Number of Animals						
		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured
				IV	III	II	I[2]					IV	III	II	I					IV	III	II	I	
50-400	60-30	74	22	0	15	4	25	8	-	27	25	2	0	0	0	0	-	-	-	-	-	-	-	-
400-700	30-18	71	1	0	16	35	6[3]	13	-	29	25	4	0	0	0	0	-	-	-	-	-	-	-	-
700-1000	16-7.5	31	0	0	3	13	7	8	-	38	30	3	1	0	0	4	-	-	-	-	-	-	-	-
1000-1800	10.5-3.5	38	0	0	3	18	14	3	65-17	99	19	10	69	4	0	-	100-65	8	5	1	1	0	0	1
1800-4000	4.5-1.5	4	0	0	0	1	3	0	30-0.4	102	0	0	49	24	23	6	80-20	51	17	9	22	0	1	2
4000-8000	-	-	-	-	-	-	-	-	5.5-2.0	22	0	0	0	0	15	7	60-30	65	1	4	42	14	4	0
8000-10000	-	-	-	-	-	-	-	-	1.5-0.5	-	-	-	-	-	-	-	26-12	41	0	0	1	9	6	25
10000-20000	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	18.5-5.5	21	0	0	3	4	14	0
Total		218	23	0	37	71	55	32		317[4]	99[4]	19	119	28	38	14		186	23	14	69	27	25	28

Notes:

[1] *U - thermal pulse, cal/cm^2. For these tables the units of measurement which were used during nuclear testing are retained.*

[2] *With first-degree skin burns scorched eyelashes and hair were also observed.*

[3] *Other animals from those which were put on the test fields and survived did not suffer burns from thermal radiation.*

[4] *Numbers do not add up; data entries are as in original. Note that totals of 317 and 99 match corresponding data points in Table 6.*

Table 16. Consequences of thermal radiation effects from atmospheric nuclear explosions of various yields on animals in open trenches.

Distance from the epicenter, m	Low Yield (W<10 kt; H = 55-265 m)								Medium Yield (W = 31-62 kt; H = 270-1,050 m)								High Yield (W = 200-1,800 kt; H = 1,000-1,500 m)							
	U (cal/cm²)[1]	Number of Animals							U (cal/cm²)[1]	Number of Animals							U (cal/cm²)[1]	Number of Animals						
		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured		Total	Killed	Injury level				Un-injured
				IV	III	II	I #					IV	III	II	I					IV	III	II	I	
50-400	60-30	42	8	0	11	2	6	15	-	15	12	0	3	0	0	0	-	-	-	-	-	-	-	-
400-700	30-18	33	0	0	0	4	2	27	-	14	3	0	3	2	0	6	-	6	6	0	0	0	0	0
700-1000	16-7.5	37	0	0	0	0	0	37	-	20	2	0	9	3	3	3	-	6	6	0	0	0	0	0
1000-1800	10.5-3.5	22	0	0	0	0	0	22	65-17	20	0	0	0	2	6	12	100-65	34	18	0	8	0	2	6
1800-4000	4.5-1.5	-	-	-	-	-	-	-	40-30	8	0	0	0	0	1	7	80-20	24	4	2	8	6	0	4
4000-8000	-	-	-	-	-	-	-	-	5.5-2.0	-	-	-	-	-	-	-	60-30	12	0	0	0	0	0	12
8000-10000	-	-	-	-	-	-	-	-	1.5-0.5	-	-	-	-	-	-	-	26-12	6	0	0	0	0	0	6
10000-20000	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	18.5-5.5	-	-	-	-	-	-	-
Total		134	8	0	11	6	8	101		77	17	0	15	7	10	28		88	34	2	16	6	2	28

Note:

[1] *U - thermal pulse, cal/cm². For these tables the units of measurement which were used during nuclear testing are retained.*

As shown in Tables 12-16, the zones of severe burn injuries from the hermal radiation for low-, medium- and high-yield nuclear munitions were located at distances of about 650, 2000, and 2,500 meters from the explosion center (epicenter), and the zones of medium severity burns from explosions of similar yield were located at distances of about 1,000, 2,200, and 6,000 meters, respectively.

Methods to treat skin burns and other pathological processes were tested during the studies. These methods are described in a number of literature sources (12-22 and others). Survival of experimental animals confirmed the efficiency of the combined therapy and particularly the combination of protective and therapeutic measures taken. The value of this therapeutic method has been proven in experiments on a large number of animals (about 300 dogs).

Many investigators maintain that it is difficult to diagnose the severity of skin burns. Determining the depth of necrosis was possible, using methods current at that time, not earlier than 10-20 days post exposure, rather than during the first few hours and days, as demanded by clinical interests. If, on the first day after the explosion, the diagnosis was "scorching of eyelashes and hair in the eye region," then it often turned out later that a first-degree eyelid burn occurred.

The investigators were very interested in studying visual organ injuries and primarily temporary blindness.

3.3 THERMAL INJURIES OF VISUAL ORGANS

During the experimental studies using animals, mainly, sheep and rabbits it was found that there can be three types of eye injuries:

1. Temporary blindness lasting several minutes to several tens of minutes.
2. Burns of the ocular fundus that can occur at considerable distances after a direct look at the nuclear explosion fireball.
3. Corneal and eyelid burns that can occur at the same distances as skin burns (see Tables 12 through 15).

Thermal injuries of the visual organs were studied in both surface and atmospheric nuclear explosion. There were eight surface explosions studied; one high yield, four medium yield, and three low yield.

Most large-scale studies were performed on November 22, 1955 at a high-yield atmospheric explosion where 123 sheep were put on the open ground (76 sheep suffered visual organ burns) and 58 sheep in open trenches (12 sheep suffered visual organ burns). No thermal injuries of the visual organs were detected in animals placed in a large number of engineering structures (trenches, dugouts, reinforced concrete chambers, blocks of stationary fire structures, armored cowls, heavy and light type shelters), armored equipment (tanks, self-propelled artillery facilities, and armored carriers), and in various houses as well.

Shaven and unshaven rabbits were put in the area of the low-yield atmospheric nuclear explosion of September 13, 1957 at a distance of 730 meters in order to specifically study the temporary blindness phenomenon that a low-yield nuclear weapon explosion would produce at night. Most other explosions, as a rule, were during the day, most frequently on a serene sunny day.

Many participants in the test and the residents of the town of Kurchatov and other settlements who watched the bright flash of the nuclear explosion during a bright sunny day without eye shielding noted a "dark spot" in the field of vision lasting several minutes after the explosion. At times a feeling of pain and discomfort arose in the eyes and persisted for one or two days. Some people complained of difficulties in reading for one or two days because the "dark spot" in their eyes impeded their vision. A longer change in vision, lasting four or five days, was noted in only one case.

Thus, there were noted no pronounced vision disorders noted among people who watched the evolution of the nuclear explosion fireball with unshielded eyes on a sunny day at a distance of more than 7-8 km from the epicenter.

After a nighttime atmospheric low-yield weapon, about 100 test participants were questioned. Much attention was paid to the location of the observer at the time of the explosion, to the use and character of eye shielding, to the direction of the gaze relative to the light flash, as well as to the character of the subjective symptoms during and after the flash and the next day. Data on the distance to the epicenter and the number of observations are presented in Table 17.

Table 17. Night nuclear explosion observers.

Distance to the Explosion Epicenter, (km)	Number of Observers
12	1
15	35
20	2
30	1
35	2
38	2
43	1
63.5	56

Of the 56 persons who watched from a distance of 63.5 km, 39 persons were without shielding glasses. Seven persons looked at a certain angle toward the explosion, 23 to the opposite side; four persons were in the shadow of houses; five persons looked directly at the explosion. Those who looked without glasses experienced the considerable luminosity of the light flash: "it became brighter than a bright sunny day."

As a rule, spontaneous eyelid closure was observed at the time of the flash. After that, observation of the continuing fireball evolution caused no subjective feelings. In a few cases

reduction of vision, pain in the eyes, and presence of dark circles in the field of vision were noted. All these phenomena persisted from several seconds to one or two minutes.

One person, who was at a distance of 15 km and did not use shielding glasses, looked at the flash at an angle of 90°. At the time of the flash his eyes closed, but the expression of the continuing flash persisted even with closed eyes. After the explosion he could see nothing around him for about 5 minutes.

Of interest is the following observation by a group of military men. This group of six men went by car toward the test field. About 17 km from the test field center they stopped their car and got out. The driver stayed in the car. Expecting that the explosion would occur in a few minutes, the men turned their backs to it and looked at the ground. No one had any means of shielding their eyes. The explosion was not unexpected by them. During subsequent questioning, three men from the group noted complete loss of vision for 30 seconds. One of them felt "heaviness" in his eyes for five to eight minutes, and another experienced pain in his eyes resembling rheumatic pain. One of the group noted complete loss of vision for one minute. Two or three minutes later he saw a black spot at the center of his field of vision which impeded spatial orientation. Another military man noted complete loss of vision for two minutes. Soon his vision returned completely, but two hours after the explosion he saw rainbow circles in his eyes. Other watchers, who wore shielding glasses and were at various distances from the night nuclear explosion, noted no subjective vision disorders.

After the above digression, the case in point being the subjective response of testing participants and some of the general population to temporary blindness, we return to our narration of the results of the animal experiments. During these experiments important data were obtained on the injurious effect of nuclear weapons on the organs of vision of animals, and thus on people as well.

During testing the appearance of a new visual organ injury related to nuclear weapons, chorioretinal burn (burn of the eyegrounds), was found. To a certain extent these burns resemble the burns which occur from solar radiation, for example, when watching a solar eclipse with poorly shielded eyes.

The experiments showed that for eyeground burns to occur, certain conditions had to be met. Therefore, there will not be massive numbers of this type of injury. Temporary blindness occurs more often under night conditions [23-25].

Let us now dwell on some methodologies of this research. It was mentioned above that a biological sector of the scientific research program was established at the test site in order to implement the medical/ biological research program. However, the biological sector did not have ophthalmologists on the staff. Consequently, during testing ophthalmologists and servicing personnel from various research institutions were involved in doing special jobs as part of the biological sector activities.

All studies were performed according to the general and special programs drawn up in

advance, with ophthalmologists being attached to the mission and charged with fulfillment of the special programs. The study of the injurious effect of a nuclear explosion on visual organs were performed using camels, cattle, horses, sheep, goats, dogs, pigs, rabbits, guinea-pigs, and rats. As a rule, most animals were put on the test fields by various departments of the biological sector, while rabbits and some sheep and dogs were emplaced by a special department for studying the injurious effect of nuclear weapons on visual organs. Restraint of sheep and rabbits involved securely fastening the animals with their heads toward the field center.

The visual organs of the animals were studied according to a special protocol. The visual ability of an animal was primarily judged by its behavior, a general response to light and a moving object, as well as by a pupillary response to light. Unfortunately, no sufficiently accurate and simple method to assess vision in animals existed then.

Before and after the test the ocular appendages, the anterior portion of the eyeball, deep optical sections and eyeground status were thoroughly examined. The examinations were made using a binocular magnifier, a slit lamp, and simple and electric ophthalmoscopes. The eyeground was examined using a reflex-free ophthalmoscope with the pupil being dilated with 1% solution of homatropine or atropine. To detect defects in the cornea epithelium, a 1% solution of fluorescein was used. To dilate the palpebral fissure, eyelid elevators were used. The animals were examined in a specially equipped room, as well as in vivarium rooms.

During the first two weeks after testing all animals which survived were examined. Rabbits were examined during the earliest hours after the explosion. Animals in which visual organ injuries were detected were examined every three days during the first ten days. Then the animals were examined at five to seven day intervals. The total duration of observation of the experimental animals was 20-45 days; in some cases even up to eight to nine months and more.

The examination results were recorded in detail in the case records and in worksheets.
The research performed allowed us to find out that burns of the cornea and eyelids (upper eye sections) occur at the same distances as the animals' skin burns (Table 18).

Table 18. Sizes of zones where thermal radiation injuries (skin and eyelid burns) of unshielded animals occurred after explosions of various yields at medium atmospheric transparency.

Burn Degree	Injury Zone Radius (m)					
	Atmospheric Explosions			Surface Explosions		
	Low Yield	Medium Yield	High Yield	Low Yield	Medium Yield	High Yield
3rd	800	2,500	7,000	700	2,000	2,500
2nd	1,700	3,000	9,000	1,000	2,300	6,000
1st	1,900	4,000	13,000	1,300	2,500	8,000
Hair scorching	1,900	4,300	13,000	1,800	4,000	9,000

Much attention was paid to studying the new type of visual organ injury, i.e., eyeground burns. It is interesting to note that it was not possible to detect that injury type immediately. Eyeground burns were first noted in 1953 after an atmospheric explosion of a low-yield nuclear charge. Systematic study of these injury types began in 1954.

Eyeground injuries were observed only for animals emplaced on open ground with their heads toward the explosion. The effect of eyeground burns on visual function depended on injury severity, location, and size. Burns in the region of the yellow spot and the optic disk were particularly hazardous.

The analysis of experimental results testifies to the fact that eyeground burns (chorioretinal injuries) are most probable after low-yield nuclear charge explosions and after high-altitude explosions (more than 10 km above the ground surface). Eyeground burns can be observed at distances where thermal radiation intensity is too low to cause skin burns (see Table 18). By virtue of the focusing action of the human optic system, thermal radiation can injure eyes of people who occasionally look towards an explosion. However, such times are very rare. The quantitative estimation of distances from the nuclear explosion center where such visual organ injuries are possible was of an indefinite character and was not studied during the course of test-site investigations.

The temporary loss of vision (temporary blindness), especially under night conditions when eyes accommodate to darkness and pupils are dilated, is most frequent and consequently more important from the standpoint of developing measures for eye protection. This phenomenon can take place, as the above-described experiment showed, at a considerable distance from the explosion center and can be independent of the direction of gaze at the time of detonation. The injury zone radius is largely dependent on the atmospheric state at the time of the explosion, but its value was not experimentally estimated during atmospheric nuclear testing.

3.4 DEPENDENCE OF RESEARCH RESULTS ON METEOROLOGICAL CONDITIONS AND OTHER FACTORS

Meteorological conditions during nuclear testing at the Semipalatinsk test site affected factors causing injury in several ways. We noted the following features. At the first USSR nuclear test of August 29, 1949 there was considerable cloudiness at the time of the explosion, and it had rained quite heavily at the test area prior to the explosion. Under such conditions experimental animal injury was mainly due to the shock wave and penetrating radiation. The injurious effect of the thermal radiation was largely attenuated.

During preparation and performance of one of the thermonuclear munition tests in 1955 that used an aircraft to drop the bomb, the following event took place. The test scheduled for November 5, 1955 was canceled due to weather conditions, as the epicenter region could not be observed using optical devices. The delivery aircraft returned to the base. The next day, November 6, 1955, the nuclear aerial bomb was dropped, and the nuclear explosion (200-250 kt) took place at an altitude of about 1,000 meters.

In preparation for this event a target facility was erected at the test field. It was composed of various structures and military equipment. A large number of animals of various types were emplaced in them. To study the minimal values of thermal pulses required to produce eyeground burn, 60 sheep were put at various distances by personnel from the ophthalmologic division. At the time of the explosion in the test field, low dense cloudiness and precipitation in the form of snow were observed in the area. Because of considerable absorption of thermal radiation energy there were no eyeground burns in any of the sheep, since it is well known that for these burns to occur it is necessary that a very bright image of the nuclear explosion fireball be present on the retina of the eye. Cloudiness, precipitation and the high humidity of the animals' hair cover led to higher threshold values for the thermoluminescent pulses to produce burns of the ocular appendages and anterior portion of the eye globe. At the biological point nearest the explosion epicenter (3.5 km), the thermoluminescent pulse equaled only 0.034 cal/cm^2.

At a surface explosion of a low-yield munition in the same year (1955) when studying the conditions of visual organ injury, the effect of relief shielding against nuclear explosion thermal radiation was clearly found: no eyeground burns were observed for animals shielded by hills (eminences). There were reliable experimental arguments for the specific role of meteorological conditions and shielding with local objects. These facts should be taken into consideration when assessing the degree of biological injury from thermal radiation of a nuclear explosion.

3.5 TRANSFER OF MEDICAL/BIOLOGICAL EXPERIMENTAL DATA FROM ANIMALS TO HUMANS

Results of the analysis of experimental data show that the most massive injury types from the thermal radiation effect of nuclear explosions are burns of the skin, cornea, and eyelids. When trying to transfer visual organ burn rate data obtained from animals to people, certain features

must be taken into consideration. First, human eyelids and eyeballs are better protected against thermal radiation than the eyes of experimental animals. This is related to both a deeper position of the eyeball and the presence of brows and possible shielding with a head cover. Secondly, humans can also shield their eyes with hands or some other means of shielding.

Unfortunately, at the time of the medical/biological experiments no scientifically justified technique had been developed for the transfer of the data obtained using animals to humans, i.e. a technique that would allow one to account for variations in the rates of injuries of varying degrees of severity in a strictly quantitative manner. It is in the interpretation of thermal radiation injuries that special difficulties arise.

3.6 CONCLUSIONS

The use of experimental animals was of great importance in medical and biological research studying the injurious effects of the shock wave and thermal radiation from a nuclear explosion. The role of animals in solving most biological and medical problems is invaluable. Thanks to these animals, it became possible within relatively short time periods to solve the complex problems of protection against the injurious factors of a nuclear explosion and to render aid and treatment to injured people.

This report (the first of two parts) provides the analytical results of the experiments on animals that allowed detection of disorders that occur in a live organism under the effect of an air shock wave and thermal radiation from a nuclear explosion. In order to study the biological effects, experimental animals of various types were put on open ground, in 500 field and stationary structures, in more than 200 pieces of military equipment, as well as in various-purpose dwelling and production buildings.

The results of the medical and biological studies testify for the fact that shock wave injuries should be considered as contusions of varying degrees of severity. Experimental data were used to estimate the sizes of shock wave injury zones for air and surface explosions of low, medium and high yields. Injury symptoms, clinical causes of illness and their therapeutic measures were studied.

Much work was also done in studying the injurious effects of nuclear explosion thermal radiation on animals. During the studies of surface and air nuclear explosions, animals were emplaced on open ground, in open trenches, and in closed engineering structures. The experimental data analysis results were used as the basis of estimating the sizes of zones where injuries of varying degrees of severity (hair scorching, first, second, third, and fourth degree burns in animals) for nuclear explosions of low, medium and high yield charges occurred. It was found that even open-type structures reliably shield animals from burns with thermal radiation.

The investigators were very interested in studying visual organ injuries and primarily temporary blindness, especially under night conditions when this effect showed up at

considerable distances from the nuclear explosion's epicenter. All studies of visual organ injuries were performed in special programs, directed by ophthalmologists assigned to the particular mission.

The injurious effects of air shock waves and thermal radiation on experimental animals were thus studies. As a result, on the basis of the sensitivity of various types of animals to nuclear explosions, conclusions were drawn which were of importance in reliably extrapolating the obtained data in animals to humans.

Part Two of this report will address the results of data analysis for the degree of experimental animal injuries from penetrating (primary) radiation of a nuclear explosion, as well as from radiation-type injurious factors inherent in ground contamination with nuclear explosion products (residual radiation).

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PART TWO

GENERALIZED RESULTS FROM THE EXPERIMENTAL DATA ON PENETRATING (PRIMARY) RADIATION ON ANIMALS

Introduction

In preparing for the first Soviet nuclear tests great importance was given to the medical and biological programs and to investigations into the injurious effects of new weapons impacting living organisms. Specifically, for the first test of the RDS-1 nuclear device on August 29, 1949, 1,538 animals as well as military materiel and various structures were emplaced in 14 sectors of the test field at various distances from the burst center for biological measurements. The test animals included 417 rabbits, more than 170 sheep and goats, 64 piglets, 129 dogs, 375 guinea pigs, 380 white mice and rats. [1] Of the 1,538 animals emplaced at the test field, 368 (24%) died immediately. The remaining animals were transported the same way to the vivarium and clinic for further observation and investigations of clinical injury patterns and development of treatment methods. Greatest interest was shown in the "new" injurious effect inherent only to nuclear explosions: gamma quanta and neutron flux, i.e., penetrating radiation.

The second nuclear test, RDS-2, was also produced as a ground surface explosion (on a tower) on September 24, 1951. The buildings, tanks, aircrafts and fortification structures at the test field contained 237 animals including 33 large animals such as exotic camels as well as cows and horses. Relatively complex medical and biological programs were also implemented within subsequent tests.

As in the investigations covered in the first part of this paper the generalized data are from approximately 25 nuclear tests with various yields (energy release). Since the level and specific nature of injurious effects from the nuclear explosion primarily depend on the yield (energy release), all available data are divided into three basic groups:

- low yield (1-10 kt),
- medium yield (10-100 kt),
- high yield (more than 100 kt).

The generalization of experimental data was performed separately for ground surface and air explosions. The ground surface explosions include those for which the scaled height, $\overline{H}$, is less than 35 meters; $\overline{H}$ is given by the formula $\overline{H}=H/W^{1/3}$ where H is the absolute height, and W is the energy release in kilotons TNT equivalent.

If the scaled height is greater than 35 meters the explosion was referred to as an air burst. It should be particularly emphasized that the relative significance of penetrating radiation to other effects increases as the yield decreases.

Research involving experimental animals was needed in order to extrapolate experimental data to man. About 8,000 animals, not counting laboratory mice, were emplaced at the test

fields between 1949 and 1957, which was the period of intensive medical and biological studies. Approximately 50% of the animals were sheep and dogs, which were primarily used to study the specific effects of penetrating radiation.

For determining uniform exposure to penetrating radiation from ground surface explosions, animals were used that differed in radiological sensitivity. Particularly, for dogs, rats, and rabbits the radiation doses leading to 50% lethality were 3.0±0.3 Gy, 5.8±0.6 Gy, and 7.05±1.15 Gy, respectively.[3] The radiological sensitivity of dogs and sheep is most similar to that of man as has been shown in accidents involving human exposure.

We shall consider briefly the basic specific effects of penetrating radiation impacting experimental animals.

Specific Effects of Penetrating Radiation

Penetrating radiation produced by a nuclear explosion was the external source of ionizing radiation relative to the experimental animals at the test field and represented gamma quanta (photons) and neutron flux. [4]

Gamma quanta and neutrons moving through biological tissue of animals at the test field ionized the atoms and molecules composing the living cells, which violated the normal metabolism, changed the pattern of vital cell functions, multiple distinct organs and systems, which in turn led to the initial signs of radiation disease and subsequently into full-blown radiation disease.

Gamma quanta could be spontaneous (emitted during the interaction of neutrons with structural materials of the device and the neighboring air layers), fragmentary (generated by the decay of fission fragments), or capture-driven (produced by nuclear reactions involving neutron capture by air and soil atoms at significant distances from the burst center).

Neutrons of penetrating radiation could be spontaneous (emitted from nuclear explosion reactions), or delayed (formed during the decay of the fission fragments within the first two to three seconds after the shot).

The dependence of animal radiation injury level on the radiation dose necessitated dosimetry data both to determine the relationship between the radiation injury level (ARD degree) and the radiation dose, and to serve as a diagnostic parameter.

The experiments involving animals distinguished exposure dose vs. absorbed dose. The unit of measure for the exposure dose was a non-system unit (as viewed today) - Roentgen (R). One Roentgen is a dose of x-rays or gamma radiation that generates 2.1×10^{-9} ion pairs in 1 cubic meter of air.

The current international system (SI) measures the exposure dose in Coulombs per kilogram ($1R = 2.58x \cdot 10^{-4}$ C/kg). The exposure dose in Roentgens was assumed to reliably quantify the

potential hazard of ionizing radiation for the global and essentially uniform exposure of a big animal or human body. The radiation dose recorded in air was taken to be quantitatively the same as in an animal placed near the measurement point.

The measurement of neutron radiation dose used a special unit, the Roentgen biological equivalent (rem). One rem of neutrons corresponds to a neutron flux that produces a biological effect similar to the impact of a 1R dose of x-rays. Therefore the injurious effect of penetrating radiation was determined by summing gamma (R) and neutron (rem) doses:

$$D_{\Sigma}^{0}=D_{\gamma}^{0} + D_{n}^{0},$$

where D_{Σ}^{0} is the total penetrating radiation dose; D_{γ}^{0} is the gamma dose in R; and D_{n}^{0} is the neutron dose in rem (the zero index indicates that the doses were measured in front of a protection barrier, i.e., for open ground).

Because of uncertainties resulting from the variations of animal sensitivity and poorly pronounced biological response to the radiation, as well as relatively great errors in the dose estimation and in the operation of the dosimetry systems, it was assumed that in the field of penetrating radiation (gamma quanta and fast neutrons) one Roentgen was approximately equal to one rem or rad:

$$1\text{R} \approx 1\text{ rem} \approx 1\text{ rad} \approx 0.01\text{ Gy}$$

For historical reasons we have retained the units of measure used during the time the atmospheric nuclear tests were conducted.

Returning to specific effects of penetrating radiation, we should add the following. The penetrating radiation dose greatly depends on the type of nuclear device, explosion yield and type, and the distance from the burst center.

It should be noted that penetrating radiation is the basic injurious effect of neutron weapons and one of the main effects in the event of super-low and low-yield explosions. For medium and high yield explosions, the injury radius of penetrating radiation can be smaller than that of shock wave and thermal radiation.

The investigation of the impact of ionizing radiation upon living organisms started much earlier than the nuclear field experiments. Therefore data characterizing the clinical pattern of radiological injuries of various degrees came from animal studies using radiation from reactors and other sources of ionizing radiation. [4-7]

CHAPTER 1

CHARACTERIZATION OF THE CLINICAL PATTERN FOR ACUTE RADIATION DISEASE (ARD)

1.1 RADIATION DISEASE

Animal injuries resulting from gamma and neutron emission of penetrating radiation were mainly observed from ground surface and air nuclear explosions. Ionizing radiation from high altitude bursts is almost completely absorbed by the atmosphere, whereas the ionizing radiation from underground shots is almost completely absorbed by soil.

The clinical signs of radiological injuries depended on the animal's exposure dose and were characterized by three ARD forms: cerebral, intestinal, and bone marrow types.

Cerebral disease is characterized by well-pronounced symptoms of central nervous system injury. It progresses with exposure doses exceeding 30-50 Gy. [5, 8, 9] The clinical signs of this ARD type include impaired motor coordination, convulsions, cramps, ataxia and lethargy. In all cases the outcome is lethality occurring within several hours to three days post exposure.

Intestinal disease progresses after exposure to doses in the range of 10-30 Gy. This differs from the other radiation disease forms in that the clinical pattern is dominated by injuries to the alimentary canal. The main symptoms include irrepressible vomiting, hemorrhagic flux, and dehydration. The lethality probability is virtually 100% even in the most favorable circumstances.

Nearly uniform exposure to external doses up to 10 Gy caused ARD with the pathogenesis dominated by the impairment of the hematopoietic system (lymphopenia, leukopenia, thrombocytopenia, anemia), hemorrhage, suppression of biological protection mechanisms (the immune system) and infectious complications. In addition to the radiological response observed with exposure doses 1 Gy (100 R) and below, there are four degrees of ARD for exposure doses of:

- 1-2 Gy: First degree (light),
- 2-4 Gy: Second degree (medium),
- 4-6 Gy: Third degree (severe),
- Greater than 6 Gy: Fourth degree (extremely severe).

The progress of ARD includes four periods: (1) initial or primary response; (2) latent or relatively favorable clinical period; (3) heightened-disease period (pronounced clinical manifestations); (4) recovery period (progressive normalization).

The primary response (prodromal period) usually occurs immediately after exposure to ionizing radiation. This is manifested by global asthenia, listlessness, anorexia, vomiting, flux (diarrhea) and hemodynamic aberrations. The peripheral blood in the majority of cases

demonstrates neutrophilic leukocytosis and lymphopenia. The duration of the primary response ranges from several hours to 2-3 days and depends on the radiological injury degree: the higher the dose, the shorter the latent period. The latent period, when apparent recovery is observed, demonstrates severe changes in the peripheral blood due to the bone marrow damage. The level and time of these changes allows one to evaluate the severity of the process. Hair loss (epilation) is possible in this phase. This period may last from several hours to 3 weeks.

The period of rapid development in ARD primarily relates to the depression of the hematopoietic system. The animals demonstrate dramatic listlessness including prostration, low appetite or no appetite at all, progressive decrease in body weight, paleness of mucous membranes, salivation, vomiting, hemorrhagic phenomena, higher body temperature and multiple neuralgic changes. Frequently this period is characterized by possible infectious complications; quinsy, stomatitis, gingivitis, pneumonia, etc. The hematopoietic system demonstrates the greatest levels of depression. This height of the disease period lasts from several hours in the event of rapid death to 2 or 3 weeks.

Recovery is considered to begin with the restoration of the hematopoietic system. The level of leukocytes (granulocytes) and thrombocytes is increased, and reticulocytes appear. Hemorrhage of the skin and mucous membranes is reduced. The injured animals demonstrate increased activity and the recovery of appetite. At the same time the bald spot persisted along with alterations in the vegetative nervous system. The duration of the recovery period ranged from one or two weeks to several months. The animals were observed during the entire period.

During the preparation of the medical and biological programs and their methodical support descriptions were generated for the clinical signs observed in the various degrees of ARD. First degree radiation disease (light) is characterized by poorly pronounced primary response or no response and in some cases by a long latent period (up to 2-2.5 weeks) and slight short-time alterations at the disease peak. Hemopoiesis is slightly suppressed during the initial three to nine days. The number of leukocytes does not decrease to less than 2,500-3,000 per cubic millimeter. The clinical state and blood generation must recover to the norm by day 15 to 20 post exposure. If the injured animals also had secondary injuries such as burns, radiation burns of the skin, trauma, complications from infection, etc., the radiation disease duration was somewhat lengthened; the outcome, however, was usually favorable.

The second degree radiation disease (medium) typically demonstrates a short primary response (prodrome) with a long latent period (1.5-2 weeks). The disease peaks in the majority of cases with well pronounced clinical anomalies: listlessness, reduced appetite, decreased body weight, digestive disorders, higher temperature, and slight hemorrhagic phenomena. All of these anomalies progress slowly and do not reach a high intensity. Inflammation and necrotic processes are not observed in the majority of cases. The hemopoietic system is suppressed from the first day post exposure for up to two weeks. For uncomplicated disease progression, the number of leukocytes must decrease to no less than 1,000-1,500 per cubic millimeter. The recovery period usually begins around day 15 to 21

post exposure. Prognosis can be doubtful especially when complications that contribute to mortality occur.

The third degree (severe) radiation disease is characterized by a well pronounced primary response. The latent period may last several hours to a few days, or may not even occur. This injury level demonstrates all of the typical signs of radiation disease. Hemorrhagic phenomena are pronounced, especially in the skin, mucous membranes, nose and gums, hemorrhagic flux (bloody diarrhea), and vomiting. All these phenomena usually progress combined with fever, hypotension, and dehydration. The hemopoietic system is dramatically suppressed from the first day. A significant leukopenia develops between day three and day 12 post exposure. The number of leukocytes is lower than 500-1,000 per cubic millimeter in the majority of cases. Neutrophils sometimes disappear from the peripheral blood. The marrow becomes empty by day five to seven with smears of the sternum puncture material containing only plasma cell precursors or reticuloendothelial cells. The majority of injured animals die between day five and day 12 post exposure.

Fourth degree (extremely severe) radiation disease are characterized by rapid progression, making it impossible to distinguish individual disease stages. The disease begins with a well-pronounced primary response which may have a short latent period or none at all. The clinical pattern is dominated by marked adynamia, a complete lack of appetite, irrepressible vomiting, bloody flux (diarrhea) and sometimes a lower body temperature. Hemorrhagic phenomena and fever are slightly pronounced in the majority of cases. The peripheral blood demonstrates marked lymphopenia from the initial hours post exposure. The lymphocyte count drops to zero by the end of the first day. The leukocyte count falls to below 500 per cubic millimeter during the first three to four days post exposure. Ten per cent of the injured animals with fourth degree radiation disease die outright, with the majority dying by the fourth or fifth day.

Severe and extremely severe ARD is characterized by rapid stages of progression as well as deep suppression of erythro-, thrombo-, and leukopoiesis. In addition, dehydration may result in a relative increase in erythrocytes, hemoglobin and thrombocytes. The disappearance of neutrophils from the peripheral blood indicates significant clinical anomalies.

For diagnostic evaluation, the following is a list of basic pathologic and anatomical changes observed in animals at different stages of radiation injury:

1. When the animals died by the fourth or fifth day (with exposure doses ranging from 15-50 Gy), the pattern of pathologic anatomy was dominated by significant necrotic processes in several organs and tissues, especially in the small intestine and liver.
2. Deaths that occurred by the sixth to eighth day post exposure (with doses ranging from 5- 15 Gy) were characterized by necrosis observed primarily in the small intestine.
3. For deaths that occurred by the ninth to tenth day post exposure (dose range 2-7 Gy) the morphologic pattern is dominated by dystrophy and atrophy in various organs and tissues.
4. In deaths that occurred more than ten days post exposure the animals demonstrated well-pronounced hemorrhagic syndrome and dystrophic changes.

Observations of the animals in a clinical setting noted a variety of parameters characterizing their clinical state as well as their blood patterns, urinalysis results, and microbiological data (bactericidal skin pattern, altered blood precursors, etc.).

Great importance within the medical and biological programs was given to an integrated approach for choosing the treatment scheme, prescribing of medicine, and selection of ways for achieving the best therapeutic effect. This treatment should be accomplished while keeping a diet of food that is mechanically and chemically favorable and contains the desired amounts of proteins, carbohydrates, and vitamins.

Permanent arrangements were made for the extrapolation of all data to humans, with an emphasis on generic differences between animals and man.

1.2 THE ROLE OF GENERIC DIFFERENCES

It was essential during the preparation and implementation of the medical and biological programs under nuclear testing to evaluate generic differences among the animal models. However, only nonstochastic somatic effects were considered. (10-15). The need to investigate these deterministic effects was due to the demands of civil defense relating to the estimation of consequences resulting from human exposure in emergency situations and in severe radiological accidents. (16)

The generalized data relating to the consequences of severe external exposure experienced by various animal types when the dose was accumulated within one day allowed us to generate a radiological sensitivity scale for the experimental animals. This scale also defines the position of man in ascending order of sensitivity:

rabbit → rat → mouse → monkey → guinea pig → sheep → (man) → dog

It was found that for rabbits the exposure dose for which 50% of animals died within 30 days was 7.0 Gy, and for dogs 2.33 Gy. These are the extreme values of the radiological sensitivity scale. This scale is suitable for the evaluation of generic differences among animals in the event of severe total exposure. Man is placed between the sheep and dog on this conditional radiological sensitivity scale. Therefore during the experiments the exposure consequences for sheep and dogs were extrapolated to man without any correction coefficients.

In territories contaminated with nuclear explosion products (residual radiation), the accumulation of radiation dose is extended in time so that it is more reasonable to use the approximate radiological sensitivity scale obtained for chronic exposure of experimental animals. This has the following form in ascending order:

rat → mouse → rabbit → dog → sheep → (man) → guinea pig

As shown in reference 16, the highest radiological sensitivity was demonstrated by guinea pigs in terms of the impact of chronic ionizing radiation with a dose rate of about 0.5 Gy/day.

The total doses leading to mass lethality of guinea pigs, rabbits, and mice were 18, 43 and 70 Gy, respectively. No rat deaths were observed even with 90 Gy. Moreover no signs of radiation disease were found.

What is important is that under conditions of chronic exposure the radiological sensitivity of man is comparable with that of dogs and sheep. Dogs and sheep were thus the animals most extensively involved in the experiments.

The reports containing the discussion of results obtained from medical and biological programs indicated that the clinic and hematology research efforts were based on the experimental data obtained for dogs, since "among all the animals used the dogs demonstrate the radiation disease pattern that is most similar to that of man. As for the clinical pattern of radiological injury progress for other animal types only specifics observed is indicated." (17)

1.3 THE DEGREE OF ANIMAL INJURIES RESULTING FROM PENETRATING RADIATION FOR VARIOUS EMPLACEMENT CONDITIONS

The medical and biological research data obtained from the Soviet tests of nuclear weapons are diversified and to some extent not reproducible. They are important both scientifically and practically.

These research efforts led to the elucidation of the basic injury types for animals that experienced the effects of nuclear explosions. These injury types include:

1. acute radiation disease.
2. contusion.
3. thermal radiation burns.
4. acute radiation disease combined with contusion, traumas, burns and other physical damage resulting from the penetration of radioactive materials and skin contamination, as well as various combinations of the above injuries.

It was especially essential to find the primary clinical signs in the interests of early diagnosis of radiological injuries produced by penetrating radiation from nuclear explosions.

Investigation of the effects of penetrating radiation was performed for ground surface and atmospheric nuclear explosions. The experimental animals were placed at various distances from the burst point on open ground, in war materiel items, and in various types of buildings that were open and closed.

It should be noted that the investigation into the injurious effects of penetrating radiation produced by nuclear explosion essentially involved gamma quanta and neutron fluxes and was very difficult, since the effects recorded depended on multiple factors. For example, the difficulties in this research are associated with the fact that the injurious effects of penetrating radiation depend on the explosion yield (TNT equivalent) and on the design of the specific nuclear charge, as well as on the variations of the ratio between gamma and neutron doses depending on the distance, with the reliability and efficiency of recording ionizing radiation

using various dosimetry systems, the propagation of ionizing radiation in different media, and penetration of protective structures, etc.

Therefore, the data recorded could not generate statistically credible conclusions. Nevertheless, size measurements of the zones affected by penetrating radiation corresponding to the various degrees of ARD and the necessary medical and biological studies were performed.

1.4 GROUND SURFACE NUCLEAR EXPLOSIONS

For ground surface low yield explosions, the penetrating radiation effect on experimental animals was studied for three events: the 4 kt explosion of October 5, 1954; the 5.5 kt shot of March 25, 1956; and the 11.6 kt explosion of August 2, 1955. (18)

For the 4 kt explosion, the total number of injuries resulting from penetrating radiation was dominated by lethal cases. All animals positioned up to 900 m from the burst center died from extremely severe ARD. At 1,050 m, the experimental animals were affected by second degree radiation disease with a total dose of 140 R. The 5.5 kt explosion resulted in all animals at distances up to 700 m being affected by extremely severe ARD with radiation doses exceeding 2000 R. The third- and first-degree of radiation disease were observed at 800 and 1,000 m, respectively. At distances greater than 1,200 m no ARD was recorded.

For the 11.6 kt ground explosion, fourth-degree radiation disease occurred with radiation doses of 4,200-16,000R and led to lethality within two to five days. The zone radius for these injuries extended to 800 m. At a distance of about 1,000 m the animals were affected by third- degree ARD with a radiation dose of 1,250 R, and first-degree radiation disease occurred at 1,250 m with about 300 R. A slight lymphopenia due to the radiation reaction was observed at 1,500 m from the burst center with 70-80 R.

For ground surface medium yield explosions, the features of ARD emergence were also studied with three events: 22 kt shot of August 28, 1949; 26.5 kt explosion of August 24, 1956; and a 38 kt explosion of September 24, 1951. (18) It should be noted that the test of August 29, 1949 was the first Soviet shot and no classification existed for the various degrees of ARD. The same was true for the field dosimetry devices for biological experiments. Therefore it is impossible to evaluate the zone sizes for the penetrating radiation injuries of animals affected by ARD. It can be only noted that the ARD occurred from 1,500 m with a radiation dose up to 250 R.

During the 26.5 kt nuclear explosion the animals at distances of 900-1,000 m were affected by fourth-degree ARD with radiation doses ranging from 2,700 to 8,000 R. Third-degree radiation disease was observed at 1250-1500 m with a dose of about 800 R. Second-degree radiation disease occurred at 1500 m (D_{Σ}^{0}= 200 R) and first-degree radiation disease was found at 1,600-1,700 m (D_{Σ}^{0} =112-155 R). A radiation reaction affected those animals at more than 1,800 m from the burst center.

For the ground surface explosion with 38 kt TNT equivalent, fourth-degree radiation disease was observed at 1,000 m where the radiation dose was 6,000 R. Third-degree radiation disease occurred at 1,250 m (D_Σ^0 = 1500 R), and second-degree disease was observed at 1,500 m (D_Σ^0 = 400 R). No radiological injuries were recorded at 1,750 m where the radiation dose reached 100 R.

The ground surface explosion with 400 kt TNT equivalent did not involve a large scale medical and biological program. The test field contained 205 large animals, including 52 emplaced on the open ground, 42 in open trenches, 101 in closed engineering structures and 10 in war materiel items. Animals that were emplaced on open ground were impacted by penetrating radiation at 2,750 m from the burst center. This seems to be the limiting distance at which penetrating radiation impact is possible because of absorption of gamma quanta and neutrons by air. All animals removed from the 2,000-2,500 m area were affected by severe and extremely severe ARD. At distances of less than 1,800 m all the animals on the open ground were killed immediately because of combined injuries.

The consequences of penetrating radiation impact on experimental animals on open ground at various ranges from the centers of low, medium and high yield ground explosions are given in Table 19. The total number of large animals on open ground was 431; 265 of them were killed immediately and the remaining 166 were affected by ARD of different degrees.

Table 19. Consequences of penetrating radiation impact on experimental animals placed on the open ground during surface nuclear explosions with various yields.

Range, m	Low Yield						Medium Yield						High Yield					
	D_{Σ}^{0}, R[1]	Number of Animals					D_{Σ}^{0}, R	Number of Animals					D_{Σ}^{0}, R[3]	Number of Animals				
		Total[2)]	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	>16000	35	0	3	0	0	-	-	0	0	0	0	-	-	-	-	-	-
440-700	16000-2100	40	12	28	0	0	>96000	12	0	0	0	0	-	-	-	-	-	-
730-1000	4200-220	28	3	22	0	3	26000-3600	39	24	0	0	0	-	6	0	0	0	0
1050-1800	300-16	30	0	0	3	6	1520-55	61	0	17	26	6	-	13	0	0	0	0
1900-4000	-	-	-	-	-	-	30-0.05	115	0	0	0	0	-	27	2	5	1	5
4100-8000	-	-	-	-	-	-	<0.05	19	0	0	0	0	-	6	0	0	0	0
Total		133 (80)	15	53	3	9		246 (73)	24	17	26	6		52 (13)	2	5	1	5

Notes:

1. *D_{Σ}^{0} - total dose of penetrating radiation on the open ground, R (rem).*
2. *The table indicates the total number of animals at the given range. The number of animals killed prior to their removal from the site is not given since the death was caused not only by the radiation (combined injuries). Totals of animals with radiation disease alone are in parentheses.*
3. *No penetrating radiation dose data are available.*

The analysis of Table 19 reveals inappropriate efficiency of animal emplacement at the test field in terms of acquisition of maximum useful data on the laws governing the injurious effects of penetrating radiation. For example, the results of the medium and high yield nuclear explosions were that all animals on the open ground at short ranges died from mechanical trauma and thermal radiation; at long ranges they were not affected at all and therefore did not yield any useful information about the injurious effects of penetrating radiation. This practical experience allowed us to make appropriate conclusions and later this drawback was corrected to some extent. Accordingly only data describing degree of injury are recorded in Tables 19-26; data for killed and completely uninjured animals are not recorded.

Research results on the injurious effects of penetrating radiation on animals in open trenches are presented in Table 20. For low yield explosions there was a decrease in the scale of third- and second-degree ARD for animals in trenches by a factor of two on average as compared to those on the ground. It was also found that the protection properties of trenches greatly depend on the orientation relative to the radiation direction. Maximum protection level was observed whenever the given trench segment was perpendicular to the direction of photon and particulate radiation.

It is interesting to note that during the nuclear test of August 2, 1955 the animals on the open ground and in trenches were affected not only by penetrating radiation but also by radioactive fallout from the explosion cloud (residual radiation). The total exposure doses reached 25,000 R which resulted in ARD and rapid death of animals at ranges up to 1000 m.

For the medium yield explosion of August 29, 1949 (22 kt), 62 animals (31 dogs, 11 sheep, 20 rabbits) were emplaced at 950 m in an open trench reinforced with concrete blocks. All the animals (except for 3 rabbits killed immediately) died because of ARD by the 15th day after the shot. A t 1,000 m, two trench types (with the internal surface covered by poles or by reinforced concrete blocks) contained 115 animals: 16 sheep, 39 dogs, 57 rabbits, one piglet and two guinea pigs. Researchers attributed the death of 17 animals to penetrating radiation. At greater ranges no penetrating radiation impact was recorded.

The results of the high yield explosion (W=400 kt) when the first thermonuclear device was tested do not require special explanation because there were few biological tasks.

The consequences of penetrating radiation effect on the animals in closed fortification structures (covered trench segments, breastwork shelters, light and heavy shelters constructed of wood and soil, etc.) at various ranges from the ground surface explosion center are given in Table 21. The engineering structures contained 634 animals with 107 of them demonstrating ARD of various degrees.

Table 20. Consequences of penetrating radiation impact on experimental animals placed in open trenches during surface nuclear explosions with various yields.

Range, m	Low Yield						Medium Yield						High Yield					
	D_Σ^0, R[1]	Number of Animals					D_Σ, R	Number of Animals					D_Σ, R[4]	Number of Animals				
		Total	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	25000-9600	30	10	2	0	0	>1000	10	0	0	0	0	-	-	-	-	-	-
440-700	15000-230	24	18	4	2	0	>9500	10	2	0	0	0	-	-	-	-	-	-
730-1000	4200-55	28	9	13	-	6	950-110	36/ 170[2)]	1	22/62	0	0	-	12	0	0	0	0
1050-1800	-	-	-	-	-	-	100-1.5	40[3)]/ 94	0	0	0	0	-	18	6	4	0	0
1800-4000	-	-	-	-	-	-	0.05	4	0	0	0	0	-	12	0	0	0	4
4100-8000	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-
Total		82	37	19	2	6		100/ 264	3	22/ 62	0	0		42	6	4	0	4

Notes:

1. *D_Σ- total penetrating radiation dose inside the structure, R (rem).*
2. *The numerator corresponds to the number of animals in pole-supported trenches; denominator is the number of animals in reinforced concrete trenches.*
3. *At 1050-1800 m, two sheep died out of 40 animals in pole-supported trenches. They were located in the trench segment oriented along the radiation direction.*
4. *No penetrating radiation dose data are available.*

Table 21. Consequences of penetrating radiation impact on experimental animals placed in closed engineering structures during surface nuclear explosions with various yields.

Range, m	Low Yield						Medium Yield						High Yield					
	D_Σ, R	Number of Animals					D_Σ, R	Number of Animals					D_Σ, R[3]	Number of Animals				
		Total	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	785-0.35[1]	26	2	6	2	4	5400-0.6[2]	64	1	0	0	2	-	15	0	0	0	1
440-700	2094-4	19	1	6	0	4	6100-2	127	10	22	4	0	-	8	0	2	0	0
730-1000	133-18	17	0	2	1	2	867-0.2	122	2	6	0	1	-	21	3	4	0	0
1050-1800	-	-	-	-	-	-	120-1.02	129	0	9	0	1	-	28	0	0	2	6
1800-4000	-	-	-	-	-	-	0	26	0	0	0	0	-	22	0	1	0	0
4100-8000	-	-	-	-	-	-	-	-	-	-	-	-	-	10	0	0	0	0
Total		62	3	14	3	10		468	13	37	4	4		104	3	7	2	7

Notes:

1. *At 300 m, the radiation dose was 0.35 R for a permanent strongpoint pillbox, 785 R for a log frame shelter, 7 R for a wood-soil shelter.*
2. *At 250 m, the radiation dose was 5400 R for a ground surface reinforced concrete structure, 1,000 R for a 40 mm armored hood.*
3. *No penetrating radiation dose data are available.*

For low yield nuclear explosions, the penetrating radiation impact on animals in closed engineering structures was observed at 500-700 m with the radiation dose inside the structures ranging from 130 to 2,100 R. For medium yield explosions, radiation injuries of animals were recorded in closed structures at ranges of up to 1,300 m while these ranges reached 1,500 m for high yield explosions.

Closed light engineering structures reduce on average the injury zone size by 1.7-1.8 times as compared to the open ground; this coefficient is 2.0 to 2.5 for heavy structures. Brick and wooden buildings, especially the rooms oriented toward the explosion, only slightly reduce the penetrating radiation effect and hence the penetrating radiation impact zone size.

The consequences of penetrating radiation impact of animals in war materiel (T-34, T-54, IS-3 tanks; SU-152, SU-100, SU-122 self-propelled artillery systems; armored personnel carriers; IL-10, IL-2, LA-11, PE-2, TU-2 aircraft) at various ranges from the burst center are given in Table 22. The war materiel contained 182 animals with 97 of them affected by ARD of various degrees.

The tests showed that war materiel has poor protection properties especially in terms of protecting against the neutron component of penetrating radiation.

Table 22. Consequences of penetrating radiation impact on experimental animals placed in war materiel items during surface nuclear explosions with various yields.

Range, m	Low Yield						Medium Yield						High Yield					
	D_Σ, R	Number of Animals					D_Σ, R	Number of Animals					D_Σ, R[4]	Number of Animals				
		Total	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	62800-10900	21	2	4	0	0	>85000	7	0	0	0	0	-	-	-	-	-	-
440-700	13930-630	15	12	3	0	0	85000-4200[1]	14	14	0	0	0	-	-	-	-	-	-
730-1000	2700-575	8	4	4	0	0	18900-20[2]	46	11	18	2	8	-	-	-	-	-	-
1050-1800	-	-	-	-	-	-	1100-1.5	32	0	11	0	0	-	10[5]	0	4	0	0
1800-4000	-	-	-	-	-	-	76-1.1[3]	29	0	0	0	0	-	-	-	-	-	-
4100-8000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		44	18	11	0	0		128	25	29	2	8		10	0	4	0	0

Notes:

1. *The radiation dose was 85 R in an IS-3 tank at 500 m for the 22 kt explosion of August 29, 1949 [18] and 4,200 R for the 38 kt explosion of September 24, 1951.*
2. *The radiation dose was 20 R for an IS-3 tank in entrenchment at 1,000 m and 10,000 R for a PE-2 aircraft at 750 m.*
3. *No penetrating radiation was recorded for IL-10, LA-11, PE-2, IL-12 aircraft at 3,000-3,500 m.*
4. *No penetrating radiation dose data are available.*
5. *The animals were in T-34 and T-54 tanks and also under them.*

1.5 ATMOSPHERIC NUCLEAR EXPLOSIONS

For atmospheric nuclear explosions with different yield, the specific effects of penetrating radiation on the animals are given in Tables 23-26.

Table 23. Consequences of penetrating radiation impact on experimental animals placed on the open ground during atmospheric nuclear explosions with various yields.

Range to explosion center, m	Low Yield							Medium Yield						High Yield					
	D_Σ^0, R[1]	Number of Animals						D_Σ^0, R	Number of Animals					D_Σ^0, R	Number of Animals				
		Total[2]	Injury degree						Total	Injury degree					Total	Injury degree			
			IV	III	II	I				IV	III	II	I			IV	III	II	I
75-400	36600-125	73	0	46	5	0		>4000	27	0	2	0	0	-	-	-	-	-	-
440-700	200-33	73	4	53	0	5		3500-1650	29	0	4	0	0	-	-	-	-	-	-
730-1000	500-10	31	0	17	4	4		4300-800	36	7	2	0	0	>75	2	0	0	0	0
1050-1800	80-0.5	23	0	2	3	1 7		1800-75	102	9	32	23	7	73	4	0	0	0	0
1800-4000	-	-	-	-	-	-		50-16	102	0	0	0	3	50-3.5	53	0	0	0	0
4000-8000	-	-	-	-	-	-		<10	22	0	0	0	0	<1	79	0	0	0	0
8000-1000	-	-	-	-	-	-			-	-	-	-	-	<0.1	48	0	0	0	0
Total		200 (160)	4	118	12	2 6			312[3] (89)[3]	16	40	2	8		186 (0)	0	0	0	0

Notes:

1. D_Σ^0 - *Total dose of penetrating radiation on the open ground, R (rem).*
2. *The table indicates the total number of animals at this range. The number of animals killed prior to the removal from the field is not given since these deaths were mainly caused by combined injuries. Totals of animals with radiation disease are in parentheses.*
3. *Numbers do not add up; data entries are as in original. Compare with Tables 6 and 15.*

Table 24. Consequences of penetrating radiation impact on experimental animals placed in open trenches during atmospheric nuclear explosions with various yields.

Range to explosion center, m	Low Yield						Medium Yield						High Yield					
	D_Σ, R	Number of Animals					D_Σ, R	Number of Animals					D_Σ, R[4]	Number of Animals				
		Total	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	20100-5400	44	4	32	0	0	>20000	15	3	0	0	0	-	-	-	-	-	-
440-700	1000-230	33	4	16	3	5	20000	14	5	0	0	0	>10000	6	0	0	0	0
730-1000	180-40	35	0	12	5	4	4000-950	20	7	9	2	0	>5000	6	0	0	0	0
1050-1800	10-1	30	0	0	2	2	130-5	20	0	0	2	2	4000-20	34	2	6	0	1
1800-4000	-	-	-	-	-	-	<5	8	0	0	0	0	45-0.4	24	0	2	2	2
4100-8000	-	-	-	-	-	-	-	-	-	-	-	-	<0.4	18	0	0	0	0
Total		142 (89)	8	60	10	1 1		77 (30)	15	9	4	2		88 (15)	2	8	2	3

Note:

D_Σ - Total dose of penetrating radiation on the open ground, R (rem).

Table 25. Consequences of penetrating radiation impact on experimental animals placed in closed engineering structures during atmospheric nuclear explosions with various yields.

Range to explosion center, m	Low Yield						Medium Yield						High Yield					
	D_Σ, R[1]	Number of Animals					D_Σ, R	Number of Animals					D_Σ, R	Number of Animals				
		Total	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	-	25	0	12	2	5	>5000	14	4	0	0	0	-	16	0	0	0	0
440-700	-	33	0	2	1	1	>1000	16	4	4	0	0	-	22	0	0	0	0
730-1000	-	32	0	0	0	0	1015-520	18	0	7	0	1	37[2]	16	0	0	0	0
1050-1800	-	34	0	0	0	5	150-9	10	0	0	0	0	1400[3]	12	0	2	0	0
1800-4000	-	4	0	0	0	0	-	-	-	-	-	-	8-1	20	0	0	0	0
4100-8000	-	-	-	-	-	-	-	-	-	-	-	-	<1	7	0	0	0	0
Total		128 (28)	0	14	3	1 1		58 (20)	8	11	0	1		93 (2)	0	2	0	0

Notes:

1. *No data for penetrating radiation dose are available.*
2. *The radiation dose is measured inside the log frame shelter.*
3. *The radiation dose is measured inside the reinforced concrete structure.*

Table 26. Consequences of penetrating radiation impact on experimental animals placed in war materiel items during atmospheric nuclear explosions with various yields.

Range to explosion center, m	Low Yield						Medium Yield						High Yield					
	D_Σ, R[1]	Number of Animals					D_Σ, R	Number of Animals					D_Σ, R	Number of Animals				
		Total	Injury degree					Total	Injury degree					Total	Injury degree			
			IV	III	II	I			IV	III	II	I			IV	III	II	I
75-400	>10000[1]	55	2	36	3	2	>23000[1]	2	0	0	0	0	-	-	-	-	-	-
440-700	400-37	51	0	26	6	4	23000-5200	14	6	6	2	0	-	-	-	-	-	-
730-1000	<35	10	0	3	1	0	4400-1700	26	6	12	4	0	-	-	-	-	-	-
1050-1800	<5	10	0	0	0	1	200-20	18	0	1	1	6	930[2]-0,6[3]	38	0	4	3	9
1800-4000	-	-	-	-	-	-	<20	15	0	0	0	0	36-3.4	34	0	0	0	2
4100-8000	-	-	-	-	-	-	<5	2	0	0	0	0	<1	30	0	0	0	0
Total		126 (84)	2	65	10	7		77 (44)	12	19	7	6		102 (18)	0	4	3	11

Notes:

1. *Radiation dose measured inside a T-34 tank.*
2. *Radiation dose measured inside an SU-100 self-propelled artillery system.*
3. *Radiation dose measured on the bottom of the slit trench under an SU-100 system.*

The above data indicate that for low yield atmospheric and ground surface explosions the penetrating radiation impact zones are nearly comparable with those of unprotected animals. Third- degree radiation disease was observed for animals within an average radius reaching 750 m with the radiation dose up to 400-450 R; medium (second) degree radiation injuries occurred at ranges up to 950 m; and light (first) degree injuries were found at 1,100 m with the radiation dose about 100 R.

The same can be noticed for medium yield air and ground surface explosions; however the penetrating radiation impact zones are somewhat greater. Thus, fourth-degree ARD was recorded for animals at 1,300-1,350 m;

Third-degree radiation disease was observed from 1,450-1,500 m with the radiation dose ranging from 100-450 R. Second-degree radiation disease occurred at ranges up to 1,600 m (D_Σ =200-220 R), and first-degree disease was found at 1,750-1,800 m from the burst center (D_Σ=90-100 R).

For high yield explosions no radiation only injuries occurred for the animals on the open ground that survived at the burst time because of shock wave and thermal effects.

The protection provided by open trenches from the penetrating radiation produced by low yield atmospheric nuclear explosions turned out to be much lower as compared to ground surface explosions. Thus, for light (first-degree) radiation injuries, the ratio between the zone sizes is about two. As the radiation injury degree increases, the difference in zone sizes decreases.

For medium yield explosions, the differences in penetrating radiation impact zone sizes, for animals in open trenches, were smaller than for low yield explosions.

For high yield explosions, in the zone where the animals on the open ground were immediately killed, those in open trenches survived. However, they were later affected by ARD of various degrees: severe (third-degree) at ranges up to 2,200 m and light (first-degree) up to 2,400 m.

During the nuclear testing period it was found that the best protection from penetrating radiation is provided by closed engineering structures. The thicker the protective coating of the structure and the more complex the entrance is made to prohibit the direct impact of penetrating radiation, the better are the protection properties (see Table 25).

The evaluation of the protective properties of certain tanks did not always take into account their specific design aspects. Thus, tanks with the left board oriented to the penetrating radiation flux had the fuel containers serving as a relatively efficient absorber of neutrons. Consequently, during nuclear testing the protective properties of tanks in terms of penetrating radiation were determined only very approximately due to the lack of dosimetry data at different points of the tank space. The specific locations of animals inside the tank were not considered either.

The medical and biological experiments allowed us to perform reliable studies of specific effects resulting from the penetrating radiation, and included an examination of the clinical pattern and treatment of ARD. In addition, we gained a better understanding on what specifically can be done to protect against these effects.

1.6 DISCUSSION OF RESEARCH RESULTS

Primarily it should be noted that the use of animals to study the clinical pattern of radiation disease and combined injuries allowed us to obtain multiple and important data on the pattern and specific effects of injuries impacting the biological objects affected by various nuclear explosion effects. Obviously, the investigation of emergence, evolution and treatment of radiation disease was one of the main goals within the medical and biological program.

The research efforts allowed us to define the basic injury types for the animals impacted by nuclear explosion:

1. acute radiation disease
2. contusions
3. thermal radiation burns
4. acute radiation disease combined with contusions, traumas, burns, and organism injuries due to nuclear material penetration or skin contamination.

The research efforts allowed us to study the early diagnosis, clinical patterns, and functional changes in various organs and systems of the organism under the above mentioned injuries. In trying to diagnose radiation injuries as early as possible, the primary clinical signs were determined that were typical for the different degrees of ARD and that were necessary for subsequent successful treatment of this disease. What is particularly useful for the diagnosis of radiation injuries is the evaluation of the absolute amount of lymphocytes in blood and the neutron-induced radioactivity in the animals' blood and other tissues. These parameters, as shown by the research results, allowed us to evaluate the radiation injury level with a high degree of credibility.

An important law was found showing that induced radiation activity corresponding to a given degree of ARD level is reduced as the explosion yield increases. This relationship is due to the fact that increasing the nuclear explosion yield (TNT equivalent) results in the increase of the ratio of blast and thermal effects to radiation effects, complicating the progression of radiation disease. Also, the contribution of neutron dose, D_n, to the total penetrating radiation dose, D_Σ, decreases as the yield increases.

These data served as the basis for the combined hematology-radiometry method for early diagnosis of ARD that allowed us to accurately assess the penetrating radiation injuries. Within the research program, the clinical examination of animals was combined with the early diagnosis of injuries, thereby allowing us to develop the above mentioned combined method.

The clinical examination of animals affected by injurious effects from nuclear explosions confirmed the classification validity for the four degrees of severity for ARD. The ranges of minimum and maximum ionizing radiation doses were defined and are in nearly exact accordance with the delineated degrees of severity. The following radiation doses were matched with the corresponding degree of severity:

- Fourth-degree ARD results from an exposure dose > 1,000 R,
- Third-degree ARD results from an exposure dose 300-1,000 R,
- Second-degree ARD exposure dose range is 150-300 R,

- First-degree ARD exposure dose range is 70-150 R.

Animals receiving doses in the range of 30-70 R were considered to have a radiation reaction. The instrumentation and research methods of the mid-1950s did not reveal any anomalies in the hematological parameters of large animals (sheep, dogs) exposed to less than 30 R.

The results of the studies of ionizing radiation in the range of 10,000-15,000 R or higher and its effects on animals (which required the construction on the test field of especially strong structures with steel chambers for the animals) showed showed that these exposure doses were primarily characterized by central nervous system anomalies (the cerebral form of ARD).

The research data analysis showed that the pattern of progression of ARD is greatly influenced by a variety of factors in addition to the magnitude of the dose. These factors include: the individual radiological sensitivity of the animal, its overall health state, and anomalies relating to the impact from other effects of nuclear explosions. ARD was considered as an integrated pathological process regardless of the degree of injury.

In the clinical course of progression of ARD, some periods were defined indicating the degree of severity:

1. primary reaction period,
2. latent period, or period of apparent clinical well-being,
3. period of maximum illness or manifestation of clinical signs and symptoms,
4. resolution or recovery period.

The ARD symptoms that are typical for each period were defined as well as the specific state of peripheral blood and bone marrow for the different degrees of ARD. For example, for fourth degree ARD in dogs, the number of leukocytes was 0-500 per cubic millimeter 3-5 days after exposure; for second degree disease this value was 1,200-3,000 per cubic millimeter 7-21 days post exposure; and for first degree disease it reached 2,500-4,000 per cubic millimeter 3-14 days after exposure. Only radiation reaction was considered present if the reduction of leukocytes was not to less than 4,000-6,000 per cubic millimeter.

The number of lymphocytes in dogs was:

- 0-70 per cubic millimeter 1-4 days post exposure for fourth-degree ARD,
- 0-500 per cubic millimeter 1-12 days post exposure for third-degree disease,
- 500-1,000 per cubic millimeter 1-21 days post exposure for second-degree disease,
- 1,000-1,500 per cubic millimeter 1-14 days post exposure for first-degree disease.

For only radiation reaction, the number of lymphocytes did not reduce to less than 1,200-2,500 per cubic millimeter 1-10 days post exposure.

The principal indicators for the diagnosis of radiation injuries in dogs also included the number of erythrocytes, hemoglobin level, numbers of thrombocytes and reticulocytes, and the morphologic composition of marrow.

Studies were also performed to evaluate the functional changes in different organs and biological systems; the exposure doses varied within a wide range. In the first few days post exposure the

injured animals demonstrated well-defined anomalies in the functional state of the nervous system that increased as the radiation disease progressed.

In the event of slight radiological injuries (first-degree and to some extend second-degree ARD), there was a stable increase in reflex activity at the lower levels of the central nervous system. For severe injuries (second- and fourth-degrees) the progression of ARD progress was characterized by signs indicating permanent switching off of the central nervous system sections and release of the marrow reflexes. Additionally, other nervous system anomalies took the form of ataxia disorder, abnormal body position, hyperkinesis combined with paresis and paralysis of the extremities, attacks of decerebration rigidity, and increased "startle" reflexes in response to various external factors. These anomalies indicate injury to the brain tube and cerebellum.

An important law was found indicating that the degree of anomaly in the cardiovascular system depends directly on the severity of the radiation injury. These anomalies were most clearly demonstrated in dogs affected by third-degree ARD. They were characterized by hypotonia, dramatic changes in the pulse rate, flat heart tones, shortening on the electrocardiogram, and a depression of the isoelectric line of the S-T interval, as well as by changes in systole rhythm and frequency. The greater the dose, the earlier and more pronounced were the above anomalies. For extremely severe ARD form (fourth-degree), changes in the dogs' cardiovascular system were found as early as within two days post the exposure. X-ray studies allowed us to find and then classify three basic anomaly types in the alimentary canal:

1) hypomotor-hypotonia states,
2) hypomotor-hypertension states,
3) combined anomalies.

Typical changes were also found in the reproductive function systems and radiation disease specifics during the pregnancy period of animals with some relating pathological processes. It was found that restricting muscular work in the latent period does not change significantly the progress and outcome of ARD.

The use of special super-strong structures with chambers for animal exposure allowed us to determine the specifics of progression of ARD under the dominating neutron exposure and discrimination of the gamma component when the radiation doses were intentionally superlethal. [19]

The examination of animals showed that the progression of ARD is more complicated in this case. The latent period was shorter, the early stages of disease demonstrated more pronounced hypothermia and hemopoietic changes, especially in erythropoiesis. High doses of penetrating radiation (more than 200 Sv) resulted in severe anomalies of the central nervous system. The clinical pattern was characterized by rapid progression, with the first signs of clinical anomalies being observed within 30 minutes post exposure. [20, 21]

The reports [10, 14, 22] on the anatomic-pathological aspects of ARD under the injurious effects of nuclear explosions emphasized the description of both separate pathological processes in the organism and their diagnostic and prognostic significance. Very detailed descriptions were given for the changes in hemopoietic organs, friable connective tissue, alimentary canal, and other organ

systems. The study results for the pathological processes in exposed animals revealed the specifics of the progression of ARD that served as the basis for the classification of radiation disease in terms of degrees of severity. A separate disease form with a certain clinical pattern and morphology is represented by "death from radiation" when the organism is killed during the exposure or immediately thereafter.

For fourth-degree ARD, definitions were established for well distinguished and morphologically specific cerebral and intestinal forms of the disease. The intestinal form was divided into a necrotic and a gangrenous form. It was found that a transient form of radiation disease is possible and that the above forms are not followed by a hemorrhagic syndrome.

Observation of exposed animals showed that the third and second degrees of ARD may include any injury demonstrating a well pronounced hemorrhagic syndrome, anomalies of the hemopoietic organs, dystrophic changes on parenchymal organs, and infectious complications.

Grouping of ARD according to degrees of severity allowed for a more detailed study and description of morphologic changes in animals organs and tissues under different exposure conditions in determining the degrees of severity of pathological processes. For example, the anatomic-pathological studies allowed us to more reliably evaluate the severity of disease, the time of death, and the approximate exposure dose. These data were of very high theoretical and practical significance for the development of national radiobiology and radiological medicine.

Also important was the development of a medical complex required for the treatment of exposed animals. The use of this treatment complex contributed to significant minimization of severe morphological changes in treated animals as compared to the control group of animals exposed to the same dose. The treatment of exposed animals allowed us to eliminate infectious processes in the majority of cases.

The long (3-3.5 years) observation of animals affected by severe forms of ARD showed that they did not recover completely and long-term complications are possible.

The research efforts within the medical and biological programs gave special attention to early diagnosis and classification of injured individuals impacted by nuclear explosions as well as to the formulation of characteristics for the clinical and hematological patterns of the so called "purely" radiological injuries as well as combined injuries. These data served as the basis for corresponding instructions and guides for the diagnosis, medical triage, and treatment of acute radiation injuries. [9, 23, 24, others]

It was found that the early diagnosis of radiation injuries requires the data obtained from clinical, hematological, and radiation dosimetry studies. Great significance is given to individual dosimetry data and the peripheral blood absolute lymphocyte count. The description of the clinical pattern and hematological changes emphasized the fact that ARD progresses as an integrated process for all four degrees of severity. The clinical pattern of ARD demonstrates some periods that, depending upon the nature of expression of signs and symptoms, allow one to evaluate the degree of severity of the radiological injury.

The results obtained from the comparative experiments involving animals showed the efficiency of the methods developed for integrated therapy of ARD; especially efficacious was the combination of protective means (radioprotectors, etc.) with therapeutic drugs. The reliability of this method was found from the experiment involving a great number of animals (about 300 dogs). The recommendations for the preventive measures were based on the use of drugs introduced orally. The tested drugs did not have significant toxicity in either single or repeated administrations, and demonstrated a preventive effect in both cases. The sensitivity of animals with respect to various narcotics, anesthetics, analeptics, diuretics and other drugs was also determined.

The results characterizing the changes in the organism's reactivity after ionizing radiation exposure were somewhat unexpected. It was found that the animals affected by the injurious effects of nuclear explosions demonstrated changes in how the reacted to some drugs, either toward higher or lower efficacy of the drugs, depending on the severity of injury and the period of disease progression. For example, at the disease peak there is an increase in sensitivity to morphine, adrenaline, lobeline, corasol, and some narcotics. The usual doses of these drugs may result in toxic effects. These circumstances required a specific approach to the choice and dosage of drugs depending upon the injury degree, disease period, etc. A drastic suppression of immune mechanisms was also observed under the impact of penetrating radiation. The tissue permeability for microbes increased, bactericidal properties of biological barriers was reduced, and the phagocytic activity of cells was suppressed. Therefore the organism injury resulted in the evolution of endogenous infection and a septic state which caused lethality. However, the early introduction of antigangrenous serum prior to the evolution of ARD ensured a good preventive effect. Under these conditions the treatment results were positive.

No special role of penetrating radiation was observed for injuries of organs of sight. Some animals affected by second and third degree ARD demonstrated conjunctivitis sometimes combined with rhinitis. For the animals affected by second and third degree ARD paleness of the conjunctiva and a bluish color were observed. This phenomenon was well pronounced two or three days before the animal's death. In some cases radiation cataract evolved when the dogs were affected by second and third degree ARD.

"Pure" penetrating radiation injuries were encountered only for low yield explosions. For medium and high yield explosions, the majority of injuries were combined. Therefore, the investigation into the specifics of combined injuries, the disease progression, and the disease treatment were scientifically important.

CHAPTER 2

COMBINED INJURIES OF ANIMALS

2.1 COMBINED RADIATION INJURIES (CRI)

In early reports on the injurious effects of nuclear weapons different terms were used: *"The Atomic Bomb Injuries," "Effects of A-bomb Explosions,"* and *"The Atomic Bomb Casualties."* The best one was the *"Combined Radiation Injuries"* definition (CRI) that appeared in the middle 1950s and included the complex pattern of this pathology involving radiation in a concise generalized form.

What is meant by CRI now? Combined radiation injuries are a combination of radiation and non-radiation injuries. Injuries of that kind occurred during the experimental research period from simultaneous or sequential impacts from radiation and non-radiation factors. Injuries were characterized by synergistic effects of these factors on an animal's organism, and disease progression and outcome differed from disease progression and outcome caused by these factors separately.

Most typical CRIs were caused by the nearly simultaneous effect of injurious factors of nuclear explosions, which resulted in a combination of ARD and burns and/or mechanical traumas.

The research that had been carried out has shown that the majority of CRIs occurred after medium yield nuclear explosions (up to 60-70% of casualties).

In addition, injured and burned animals that had to remain in the area polluted by radioactive materials also got CRI from the residual radiation effect. Thus, CRI is possible, in principle, not only as a result of the simultaneous influence of nuclear weapons effects, but also in cases, when, first, the effects of ionizing radiation precedes non-radiation factors, and, second, non-radiation traumas take place before radiation injury. In the first case ("exposure-trauma" variant) more severe disease was observed as compared to simultaneous injuries or "trauma - exposure" sequence. Based on the results of medico-biological research, CRI classification has been developed with descriptions of the prominent signs.

2.2 COMBINED INJURIES CLASSIFICATION

In accordance with data obtained during the experiments it was suggested that possible losses caused by nuclear weapons effects may be divided into radiation-mechanical, radiation-thermal, and radiation-mechanical-thermal. It was also suggested that CRIs occurring at different times and that are caused by combinations of radiation exposure with bullet wounds and/or incendiary (napalm, pyrogels, etc.) burns are also related. It was advised that injuries which do not include any radiation exposure effects be referred to as combined non-radiation injuries.

The only injuries that should be classified as combined injuries are those in which the effect of each injurious factor can put the casualty (animal or human) out of action, affect his ability to function, degrade his fighting efficiency and capacity for work, or lead to a condition in which the clinical-

laboratory indices characterizing different body systems show considerable deviations from normal values. The major component is identified which can cause the most pronounced imbalance of condition of the biological systems in the pathologic process concerned. In a clinical sense, the major component of CRI is that which defines the greatest danger for the life and health of the injured person; in an organizational sense, it demands the most urgent assistance at the moment.

Four periods of CRI can be distinguished:

1. The acute period (primary reactions to radiation and non-radiation injuries),
2. Prevalence of non-radiation components,
3. Prevalence of the radiation component,
4. Recovery period.

In the course of the medical-biological program, clinical patterns and hematological changes caused by combined radiation injuries were studied, depending on the type and parameters of certain injurious factors affecting the animal. A rather detailed description is given for different forms of combined injuries with special attention being paid to the description of ARD progression against the background of contusions, trauma, and burns.

The main features characterizing combined injuries caused by the effect of injurious factors from nuclear explosions have been defined:

- The rapid development of radiation disease, the dependence between the rate of disease progression rate and the penetrating radiation dose being impossible to find out form the clinical pattern;
- The presence of changes in the organism characteristic for barotraumas, contusions, skin beta-burns, thermal burns, etc.

As a rule, the combination of radiation injury with barotrauma or especially with a contusion led to a greater severity of radiation disease progression. The clinical pattern was characterized by the presence of adynamia, uncoordinated gait, tremors, convulsions, and some illogical behavior. In these cases the development of radiation disease occurred earlier, and the clinical disorders were more clearly shown and were distinct. Animals that had been in the radioactive fallout area of nuclear ground explosions often got radiation injuries of the skin in the form of beta-burns that complicated the progression of ARD.

Pregnancy also had a considerable effect upon the development of ARD. It essential to note that in cases of third and fourth degree radiation injuries, pregnancy complicated ARD; however in first and second degree cases it alleviated the disease.

In third and fourth degree ARD, clinical patterns of adynamia and anorexia (lack of appetite) prevailed. There was also an observable lowering of the animal's body temperature, as well as paleness of the mucous membranes. Hemorrhagic phenomena were more feebly expressed. As a rule, death took place during a pathologic delivery, and there was fetal decomposition. Peripheral blood was characterized by the presence of anemia and a steady but, in a number of cases non-progressive, leukopenia. The disease prognosis in the cases of CRI always depended on the degree of injuries, the efficacy of medical assistance, and on the specific combination of major injurious factors.

2.3 RADIATION-THERMAL INJURIES

Animal skin burns resulted from the direct effect of the nuclear explosion flash (primary burns), as well as from burning cloth which simulated the wearing of a uniform or other clothing and fire flame (secondary burns). Primary burns differed considerably from each other depending on the explosion yield. In cases of low-yield nuclear explosions, burns from momentary exposure tended to be superficial; high-yield explosions burns spread considerably deeper.

In cases of combined radiation-thermal injuries more serious disorders occurred in the hemopoietic system. Changes in the hematological indices depended on the degree of burn severity as well as during the progression of ARD. In the latent period of ARD changes observed in the peripheral blood indices were mainly caused by thermal trauma, and not by the ionizing radiation effect. Depending on the area and depth of the burns, different degrees of hemoconcentration, leukocytosis (with a differential shift toward younger forms), and thrombocytosis developed. At the height of ARD the prevailing changes showed blood production depression, even as far as complete suppression. The numbers of lymphocytes, neutrophils, and thrombocytes in the blood were reduced. As a result of increased erythrocyte decay and removal, and depression of hemoglobin production, anemia developed.

During the recovery period hemogram change phasing was observed with the prevalence of shifts characteristic for that of major injuries. The important point was that hematological shifts in cases of CRI were not merely the sum of measurements observed in cases of each component trauma taken separately, but were characterized by a number of specific features. Those features were stipulated primarily by the degree of radiation and thermal effects. Thus, thermal burns combine with light and medium radiation disease (first and second degrees) to exert a stimulating effect on the hemopoietic system. This was shown by a delay in the development of leukopenia and earlier and more intense increase in the quantity of leukocytes. In cases of serious radiation injuries, burn trauma was conducive to early and more intense suppression of the hemopoietic process.

The practical value of this research was in establishing the fact that reciprocal complication syndrome did not develop in all the cases of radiation-thermal injuries. Mild burn trauma increased the organism's resistance to subsequent ionizing radiation effects. However, severe burn trauma sharply decreases the organism's resistance to radiation effects. Therefore, the organism's resistance against radiation-thermal injury can increase or decrease, which must be taken into account when determining treatment and prognosis for CRI.

In severe cases of burn radiation disease researchers observed a combined influence effect, which was later called the reciprocal compilation syndrome. This syndrome was seen in different degrees depending primarily on the reciprocal influence of injurious factors and on the interaction and compatibility of regulatory reactions. The research results give convincing evidence of the fact that in cases of combined injuries lethality was considerably higher than it was in cases of separate effect of each of the components and exceeded their total effect; i.e., effects were synergistic and not merely additive.

Increasing the degree of complication of ARD in the case of combined injury led to a local disease complication. Primarily, the exudative phase of inflammation (inflammatory perspiration) was

inhibited. In burn wounds the demarcation processes (separation of numb areas from healthy ones) were delayed down as well as necrotic tissue seizure. At the height of ARD, burned areas of animal skin showed spacious hemorrhages, secondary and tertiary necrosis, and putrescent liquification of burned tissues. The process of wound resolution was delayed with tissue decay products and microbes moving into the organism in large quantities. Wound healing went slowly.

These features of burn-radiation disease progression in cases of combined injuries became the basis for developing treatment protocols and triage standards on humans. [9, 23, 24] Injuries of the organs of sight in the experimental animals were also combined injuries in the majority of cases. The difficulty of conducting research in field conditions confirmed the expediency of conducting these studies under laboratory conditions, as well as using the ophthalmologic departments of medical colleges to study the processes and treatment of organ-of-sight diseases in cases of combined corneal injuries. From this viewpoint, experiments on preserved cornea transplants were of considerable interest.

In the overwhelming majority of cases animals located in the open space of the testing ground showed organ of sight CRIs. Shelters of different types and military equipment protected the eyes from the injurious effect of the flash. This effect on the organs of sight was decreased considerably or even completely eliminated by unfavorable meteorological conditions (snowfall, low cloudiness with fog, etc.), that caused high absorption and dispersion of the flash. Forests, irregular terrain, and other objects also had a protective screening effect. Features of the disease course and treatment for organ of sight CRIs were studied on a rather large quantity of experimental animals (about 100 dogs and 200 rabbits).

Thus, as a result of long-term and relatively expensive research into the injurious effects of nuclear explosions of different yield upon experimental animals' organs of sight, the character and frequency of injuries of organs of sight have been determined to depend on the pattern of animals' location in the experimental area. Recommendations have been developed concerning treatment of CRI of organs of sight.

2.4 RADIATION-MECHANICAL INJURIES

The experiments performed have shown that the direct effect of the nuclear explosion shock wave rarely leads to open injuries. However, if factors like terrain are taken into account, especially in forests and urban buildings, the total number of injuries can be increased.

The presence of radiation injuries, as experimental results have shown, affected the processes of cell and tissue post-traumatic regeneration, which determined the specific character of trauma and wound healing in the exposed organism.

In cases of first degree ARD, when the animal's organism was able to cope with the consequences of ionizing radiation effects, no visible disorders in wound healing were observed. The organism's immuno-biological mechanisms for protecting against wound infection were preserved in full measure. For a certain period of time (from several days to two or three weeks) wound healing occurred in the ordinary manner, and wounds that were surgically treated and sewn up were almost

completely healed before the period of radiation disease development began.

However if the progress of "pure" ARD is compared to the disease after combined radiation-mechanical injury, the radiation component being the same in terms of dose and type of exposure, then the reciprocal compilation syndrome caused by the influence of a injury or a wound is displayed by an early full-swing period, and more clearly exhibits disorders in all pathologies specific for the radiation disease, such as metabolism, hemodynamics, hemopoesis, etc. Certainly the degree to which the reciprocal complication syndrome is manifested was influenced by the nature of the mechanical traumas, their complexity being the main point. Depending upon the severity of the trauma (single or multiple injuries), substantial differences were found in the degree of reciprocal complication syndrome manifestation and in how clearly it was manifested (Table 27).

Table 27. Reciprocal influence of radiation and mechanical injuries by degree.

Acute radiation disease degree	Injuries, wounds	Reciprocal complication syndrome degree
Light (first-degree)	Single	-
	Multiple	+
Medium (second-degree)	Single	++
	Multiple	+++
Severe (third-degree)	Single	++
	Multiple	+++

Symbols:
- \- *no syndrome is shown.*
- \+ *10-20% increase in lethality.*
- ++ *30-50% increase in lethality.*
- +++ *more than 50% increase in lethality.*

Wound infection was a major factor in ARD progression in animals. The risk of infectious complications was maximal in cases of CRI and was fatal in most cases; the progressive autoinfection typical for severe radiation disease further complicated the surgical sepsis phenomena. Rapidly increasing intoxication often brought the animal's organism to the critical point.

It is noteworthy that for shock-wave cases involving all degrees of injury, animal ear disorders represented a considerable portion of the clinical patters. Special research has shown that under the effect of a shock-wave with 0.3-0.5 kgf/cm^2 overpressure[1] and an impact time of 0.7-0.8 seconds, ear-drum ruptures nearly always occurred. With a shock-wave overpressure of 0.15-0.2 kgf/cm^2 and impact time of about 0.85 seconds, ear-drum ruptures occurred in approximately one half of cases. With a shock-wave overpressure of less than 0.1 kgf/cm^2 and impact time of about 1 second, no eardrum disorders were seen. However, some animals showed reduced hearing without any visible evidence of ear-drum damage. The hearing of these animals was, as a rule, restored seven to ten days post exposure.

[1] 1.0 kgf/cm^2 = 14.2 psi

In cases of severe combined injury a pattern often appeared that resembled burn shock. Shock and other possible complications were observed in animals not only with extremely severe combined injuries, but with less severe injuries as well.

ARD took a considerably more serious form if beta-burns of skin and traumatic injuries of bones were also present. In some cases of severe combined injuries peripheral blood changes were not immediately apparent. The degree of ARD in cases of combined injuries was most precisely reflected by changes in the absolute lymphocyte count.

The main achievement of the medico-biological research conducted was the development of a treatment scheme in cases of CRI. This meant early surgical treatment of wounds with simultaneous administration of antibiotics for their optimal healing.

2.5 SUMMARY OF RECOMMENDATIONS ON THE TREATMENT OF ARD AND COMBINED INJURIES

When choosing a treatment scheme and prescribing medicines for injuries caused by nuclear explosion it is advisable to consider the following:

- degree of ARD (light, medium, severe, extremely severe);
- presence of disease complications caused by the combination of external exposure with internal contamination by radioactive materials;
- the specific phase in the clinical course of ARD progression;
- ARD features in cases of combined injuries, i.e. presence of burns, trauma, contusions, skin injuries by radiation, and concomitant conditions like pregnancy, heart conditions, etc.

One should always keep in mind the fact that the best therapeutic effects can be achieved via complex treatment, which includes:

- remedies to prevent or delay progression of early radiation reactions;
- remedies that eliminate initial changes in organs and tissues remedies;
- preparations to normalize nervous system activity;
- antibacterial remedies (antibiotics);
- remedies that restore blood production and function and that restore metabolism;
- anti-hemorrhagic remedies;
- antihistamines; and
- vitamin preparations.

Treatment of injured persons will be more successful if the following measures are taken in the shortest possible time:

- evacuation of injured persons from the radioactive contamination zone;
- decontamination of skin surface and uniform (clothing); and
- rendering of first aid for those injured by ionizing radiation: dimedrol in 0.05; glucose in 1.0; biomicine 0.3; B group vitamins; ascorbic acid 0.02 and citrin 0.02. All these preparations should be given once orally. [N.B. - Units not given in original.]

If there are thermal burns, 6-10 ml of 1% Novocain solution should be injected intravenously or intra-arterially. The skin around the burn should be treated with 0.5% liquid ammonia solution and

ethyl alcohol. Burned surfaces should be sprinkled with 0.25% Novocain solution and then with 0.5-1% imanine or penicillin solution (400,000 units per 40-50 ml of distilled water). Then a bandage with furaciline or imanine solution should be applied. Bandages should be replaced every day or every other day. Later, ointment bandages should be applied (1 g of imanine, 5 g of lanolin, 15 g of vaseline), or the burn may be left uncovered if conditions are favorable.

In the primary treatment of local traumatic injuries, the injured area should be treated with potassium permanganate, furaciline, and gramicidin solutions. In cases of fractures immobilization should be ensured.

In case of severe ARD in animals a massive blood-letting of up to 1000 ml and even more was advised as an early (within first three days) treatment measure followed by transfusion of an equal amount of plasma or whole blood. In natural experiment conditions this measure led to a 30-40% increase in survival. It was also useful to apply multiple (2-3 times) blood-letting in smaller amounts (200-300 ml each).

If no plasma or blood is available a good result in the first three days can be achieved by transfusion of blood substitutes, which should be injected twice (200-300 ml each time) following an equal amount of blood-letting.

For normalizing the central nervous system condition it is advisable to use bromide 0.1-0.3 g, caffeine 0.01-0.05 g, and barbiturates in case of sleep dysfunctions.

Antibiotics played an important role in reducing and even eliminating infectious complications, especially those that resulted from autointoxication from the intestinal and respiratory systems. The following principles were taken into account in this aspect:

- using antibiotics with a wide range of action (broad spectrum antibiotics);
- creating bacteriostatic concentrations, not only in the organism's blood and tissues, but also in the areas where endogenous infection pathogenic microbes reside. The best effect in case of ARD was given by biomycin, streptomycin injected intramuscularly together with echmoline and Novocain, and penicillin with Novocain given intramuscularly two to four times daily.

Antibiotics administration is necessary until the organism's natural resistance to an infectious condition is restored. It is advisable to continue antibiotic treatment according to clinical and microbiological indices, combining inhalatory and peroral injection. Cyclic use of antibiotics is also advisable, i.e., being prescribed alternatively.

In severe cases two or three antibiotics were administered simultaneously. In all cases of antibiotic treatment it is desirable to continue observation of the injured organism's condition using microbiological methods (blood cultures, etc.)

In case of progressive anemia during the recovery period it is advisable to increase the doses of transfused blood to 300-500 ml, packed erythrocytes up to 200-250 ml, and to reduce the periods between injections to two to three days. Blood transfusion at the height of ARD, especially in cases of pronounced hemorrhagic syndrome and acute depression of blood production, is contra-indicated, as

this procedure can worsen the patient's condition. Plasma transfusion by the dropper method can reduce hemorrhagic phenomena, improve blood production, and eliminate autoagglutination (blood corpuscles sticking together).

Prescription of leucocytine is useful, as it has a stimulating effect upon the blood production system, causing a steady growth of the number of leukocytes. Folic acid, lecithin, antianemine, and vitamin B12 are also useful.

The administration of blood production stimulators should not be performed routinely, but must take into account the patient's clinical state and his hematological indices. There is no point in injecting stimulators during the period when blood production is profoundly depressed; in general, it is best to restrict the use of all medicaments.

As research has shown, cytrine, ascorbic acid, syrup of rose hips, plasma and nettle-rash extract transfusion, as well as antihistamine preparations (dimedrol, dinesine, etc.) proved to be the best cures for hemorrhagic phenomena (bleeding and vessel permeability).

For normalization of vitamin balance in ARD treatment the use of vitamins A, B, C, P, and PP is indicated either in the form of multivitamins or separately. Injection of vitamin B6 at the height of the disease has proven to be undesirable. It is also recommended to use symptomatic measures: mouth rinsing with potassium permanganate, penicillin or gramicidin if the initial signs of stomatitis and gingivitis appear during the latent period. Symptomatic measures should be used regularly at the height of the disease; gastric juice should be given if appetite is reduced, as well as cardiac remedies (cordiamine, caffeine) and stimulators of respiration.

Complex ARD treatment should be performed in conjunction with keeping the patient on a special diet. The food should be mechanically and chemically mild and should also contain sufficient amounts of proteins, carbohydrates and vitamins. It is advisable to include beef liver, cottage cheese, sour milk, raw eggs, fresh vegetables and fruit in the diet.

The summary of recommendations given above on the treatment of ARD and combined injuries shows rather completely the results of medico-biological research that was carried out in the early 1950s at the Semipalatinsk nuclear test site. At present these recommendations are of merely historic significance. Later they were revised to a considerable extent, taking into account the results of numerous laboratory tests and experience gained by clinics working with nuclear industry facilities, where accidents of different types took place including the ones resulting in acute radiation injuries [5, 7, 8, 25-31].

Using the results obtained in the course of the medico-biological programs for test sites, a number of guides and manuals for the civil defense medical service were designed [9, 23, 24, 32-34] for use in emergency conditions. We should point out that experimental animals were also used for studying the features of the injurious effect of nuclear explosion radioactive fallout, which also belong in the category of injurious factors of nuclear explosions.

CHAPTER 3
SPECIFIC INJURIOUS EFFECTS FROM RADIOACTIVE FALLOUT OF NUCLEAR EXPLOSIONS

3.1 TERRITORY CONTAMINATION

It is known that the most severe territory contamination resulted from ground surface explosions when the maximum amount of ejecta from the cavity was entrained in the plume (cloud). During this process radioactive particles of various sizes formed and were transported considerable distances by wind.

Unlike previously considered nuclear explosion injurious effects that demonstrated their impact only in the nuclear explosion area and within a relatively short period of time, the territory contamination along the cloud trace was dangerous at distances reaching hundreds of kilometers from the burst center for several weeks and even months after the shot. The surface area of the contaminated territory with radiation levels sufficient to represent a danger for people and animals was several times greater than the zones affected by the shock wave, thermal radiation, and penetrating radiation.

Experimental animals were also used to study the injurious effects of radioactive fallout in the cloud trace. The following basic tasks were solved during these studies:

1. Risk evaluation for the penetration of various size particles inside the organism by inhalation both during passage of the contamination front (aerosol fallout from the explosion cloud) and while present on the contaminated territory after the cloud had passed.
2. Evaluation of the contamination degree of animals and agricultural products.
3. Understanding the role of skin injuries (beta burns) and their influence on ARD.

A brief characterization should be given for those principles of territory contamination that directly relate to the experiments involving animals prior to the consideration of medical and biological studies.

3.2 SOME FEATURES OF TERRITORY CONTAMINATION

Usually the term "near (local) trace" is used for the territory contaminated along the path of the ground surface explosion cloud where the major portion of radioactive material falls out with particles 30-50 μm in diameter and where unprotected biological specimens are injured even by short exposures.

The main source of radiochemical territory contamination is represented by the products (fragments) resulting from the fission of plutonium-239, uranium-235 and other isotopes. In addition, the particles falling out from the cloud contain the non-fissioned part of the nuclear fuel and induced radionuclides as depicted in Figure 1.

Figure 1. Microscopic photograph of radioactive particles from the ground surface nuclear explosion.

The fission products relating to the mid part of the periodic table have different half-lives and emit gamma quanta and beta particles as they decay. In the case of fractionation (separation) of isotopes, i.e., enrichment or depletion of the mixture with various radionuclides, depending on various factors (particle size, ratio of particles formed in the high and low temperature regions of the cloud, particle formation time etc.) the isotopic composition of particles falling to the ground may greatly differ from theory. This is particularly important for the evaluation of internal radiation doses, since inhaled biologically hazardous radionuclides (iodine, cesium, and strontium isotopes) are extremely mobile and fractionate rather well. Therefore the local trace zones near the explosion, where the large particle sizes tend to settle, are depleted in terms of these isotopes particles while the more distant zones are relatively enriched. The fractionation should be considered in the evaluation of milk contamination levels and the irradiation doses for critical organs of man and animals (thyroid gland, bone tissue etc.).

The chemical composition of radioactive particles is actually identical to that of the soil in the burst region. The specific weight of the particles is somewhat lower than that of soil because of gaseous components. The radioactive products are non-uniformly distributed over the volume of the particles and mainly concentrate in the outer layers. Therefore the activity value of a particle is determined by its surface area and is almost independent of the explosion yield.

A variety of animals were used in the medical and biological research into the consequences of radioactive fallout and the injurious effects from the cloud trace. In particular, the specificity of milk contamination and milk products was studied in field conditions when the herd was grazed in the radioactive trace. The conditions for skin beta burns were determined using piglets, whose skin

sensitivity is similar to that of man. The inhalation risk from radioactive particles both during the contamination front motion (cloud motion) and during subsequent exposure on the contaminated territory was evaluated using dogs. The evaluation of inhalation risk during the front motion used the local trace model with the basic elements shown in Figure 2.

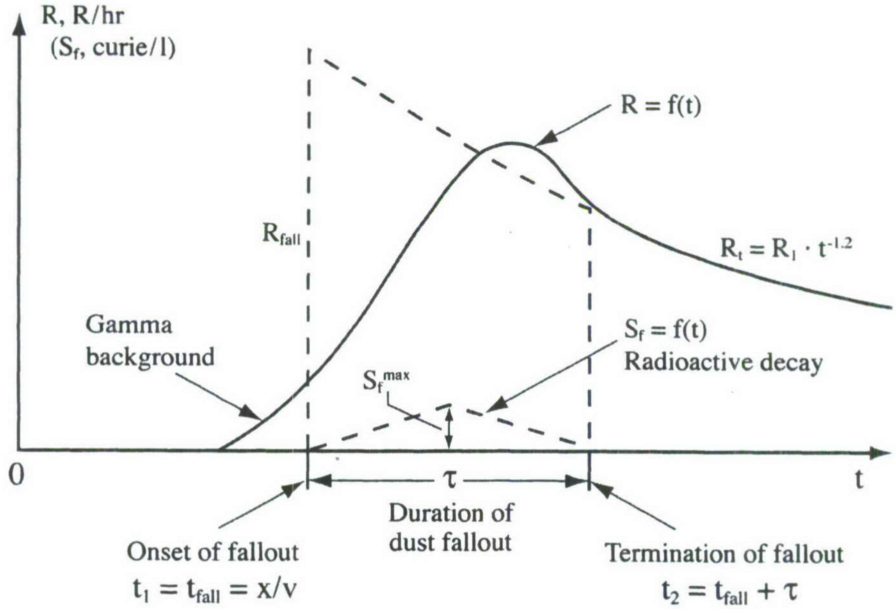

Figure 2. Time variations of gamma dose rate on the ground surface R = f(t) during the trace formation and also concentration of radioactive materials in air C_f= f(t).

The symbols in Figures 2 and 3 denote the following:

x	the distance of a given trace point from the burst point, km.
v	velocity of the average wind in the atmospheric layers from the ground surface to the upper edge of the cloud, km/hr.
C_f	the concentration of radioactive materials, in Curies/liter.
t_1	fallout start time for radioactive particles after the explosion, hr (time of arrival of cloud front).
t_2	fallout end time, hr (time cloud leaves).
$\tau = t_1 - t_2$	time of the contamination front motion above a given point, hr.
R_1	dose rate scaled to the same time after the burst, R/hr.
$R_t = R_1 \cdot t^{-1.2}$	dose rate variations according to the Way-Wigner law.

The processing of measurement data used the model characterizing, to some extent, the time variation law of the dose rate, R = f(t). The model accounted for the fact that at the time where the contamination front arrives at a given trace point ($t_1 = t_{fall} = x/v$) the dose rate seems to increase drastically to R_{fall} from the initial value and then decreases according to the Way-Wigner law. This simplified model gives the dose:

$$D_\infty = 5\, R_{fall} \cdot t_{fall}\, R$$

until the complete decay of radioactive materials.

The dose rate P_t scaled to the time after the explosion (most frequently to 24 hours) and the dose till the complete decay of radioactive products are the parameters chosen to be the basic characteristics for zoning the contaminated territory in terms of the degree of hazard for various radiation injury levels [4]. Figure 3 shows the zoning principle for the local contamination trace.

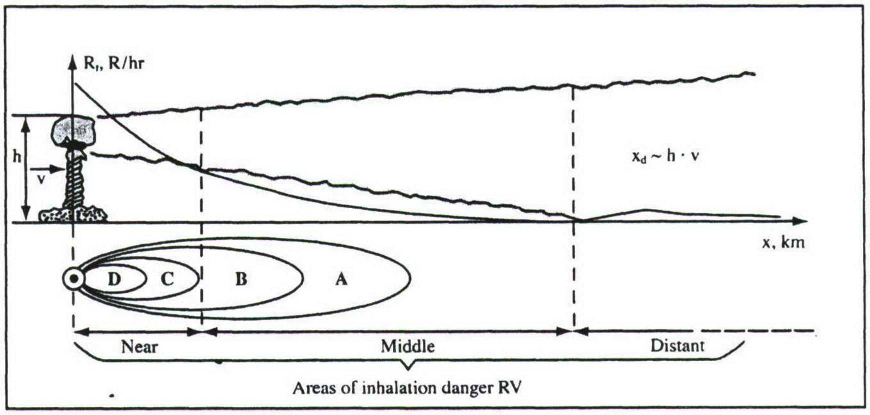

Figure 3. Contaminated territory zones along the nuclear explosion cloud trace path.

Four zones are distinguished in the trace in terms of radiation hazard:

Zone A - moderate contamination. The radiation doses until the complete decay of radioactive materials are $D_\infty = 0.40$ Gy at the outer boundary and D = 4.00 Gy at the inner boundary. The surface area comprises 70% of the total trace surface.

Zone B - high contamination. The radiation doses at the boundaries range from 4.00 to 12.00 Gy. This zone comprises 10-15% of the radioactive trace surface area.

Zone C - dangerous contamination; radiation dose can be 12.00-40.00 Gy within this zone.

Zone D - extremely dangerous contamination. The radiation doses are D = 40.00 Gy at the outer boundary and about 70.00 Gy in the center.

As the distance from the center of the ground surface explosion increases, the fraction of radioactive materials less than 50 µm in diameter, which are at risk for inhalation, also increases. In the near field of the inhalation risk (Figure 3) the fraction of inhalation risk particles increases due to near surface dust formation that is generated in the nuclear explosion region. In the far

field, the lower cloud edge may touch the ground surface, which also increases the relative inhalation risk.

From our viewpoint consideration should be given to some medical and biological aspect studies using animals in the cloud trace.

3.3 STUDIES OF SKIN BETA BURNS

In the course of research it was recognized that the problems involving the studies of skin burns can be best solved using the skin of piglets. Their skin sensitivity is similar to that of man.
To study the degree of possible skin contamination and injury effects, the piglets were emplaced in boxes that were located in the zone of expected trace path as shown in Figure 4.

Figure 4. Emplacement of experimental animals in the radioactive trace in open boxes.

From the research we found that radiation skin injuries (beta burns) complicate the progress of ARD which resulted in clinical and sometimes hematological anomalies. The following periods are distinguished in the progression of skin beta burns:

- latent period;
- intumescence (tissue swelling) or edema;
- ulcers, erosions;
- crust formation and progressive clearing of ulcers and erosions;
- formation of the upper protective layer (epithelialization).

The latent period duration greatly depended on the radiation injury level. Four levels of beta burns were determined from the research results:

1st level - a long latent period lasting two or three weeks. The basic anomalies are represented by tissue swelling. Further surface erosion or hair epilation evolve. Complete recovery was observed in one or two weeks .

2nd level - the latent period duration is four to six days. The basic anomalies are represented by intumescence, edema and erosion. Recovery occurs in two or three months.

3rd level - the latent period is four to six days. The basic anomalies involve edema, deep erosion or even ulcer with a necrotic zone. Recovery takes three or four months.

4th level - a short latent period (three to four days) with massive edema followed by deep necrotic ulcers. Usually complete recovery does not occur.

The experiments allowed us to develop recommendations for the treatment of skin beta burns and for the prevention of skin injuries. A unique experiment created by the will of nature (i.e., unplanned) was carried out in 1965 to study the degree of contamination of meat and milk producing animals in one of the contaminated areas formed by a shallow underground explosion with ejecta.

3.4 MILK CONTAMINATION

There were important integrated studies which allowed us to develop methods to assess the risk from contamination agricultural products and food prepared there from for various types of vegetation in the radiation-contaminated areas. It is known [35] that milk, a basic product of cattle, is the main portion (more than 80%) driving the entrance of radioactive materials into the human organism. The analysis results for various radiologically hazardous situations indicate that if milk contamination levels are known it is possible to evaluate the concentration of radionuclides in other cattle products such as milk reprocessing products, meat, meat products etc.

The main research efforts were performed in the radioactive trace as shown in Figure 5, formed on October 14, 1965 after a 1.1 kt nuclear explosion in borehole 1003. The depth of burst was 48 m [35, 36].

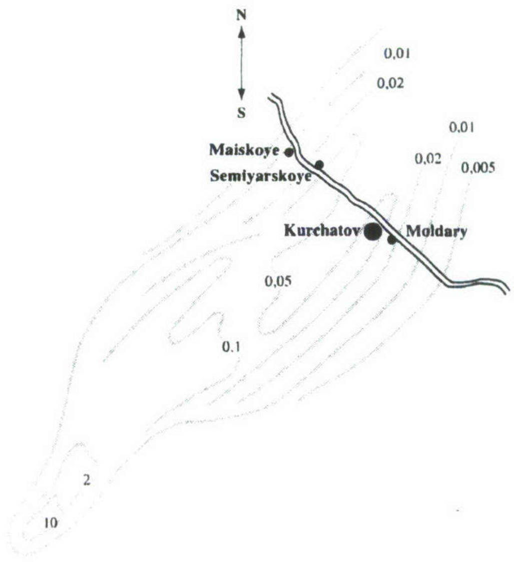

Figure 5. Schematic of radioactive trace from the underground nuclear explosion produced in borehole 1003 on 10.14.65 at Sary-Uzen area. The gamma dose rate isolines are shown in mR/hr for 24 hours after the shot.

The settlement of Moldary, which was 105 km from the explosion's epicenter, had 100 cows in lactation at the milk farm. This herd was used to study the radioactive milk evolution process.

The radiological environment at the Moldary pasture was characterized as follows: gamma dose rate was on average 0.03 mR/hr within the pasture 24 hours after the shot and the global specific activity was 87.5 kBq/kg. Table 28 contains the data on radionuclide contamination.

Table 28. Radionuclide contamination structure at the Moldary pasture.

Radionuclide	Half life	Specific activity of green grass (in Bq/kg)	Surface contamination, Bq/m^2
Strontium-89	50.5 days	$5.4 \cdot 10^3$	$8.9 \cdot 10^3$
Strontium-90	29.12 year	55.5	92.5
Zirconium-95	63.98 days	320	545
Molybdenum-99	2.75 days	$2.6 \cdot 10^3$	$4.3 \cdot 10^3$
Iodine-131	8.04 days	$2.66 \cdot 10^3$	$4.44 \cdot 10^3$
Tellurium-132	3.26 days	$5.9 \cdot 10^3$	$9.84 \cdot 10^3$
Iodine-132	20.8 hours	$3.7 \cdot 10^4$	$6.14 \cdot 10^4$
Cesium-137	30 years	91.4	152
Barium-140	12.74 days	$1.59 \cdot 10^3$	$2.64 \cdot 10^3$
Neptunium	2.35 days	$1.37 \cdot 10^4$	$2.03 \cdot 10^4$

The pasture vegetation is represented by the typical motley grass representative for this soil and climate zone of Kazakhstan. The green grass cover was on average 0.4 kg/m^2. When at pasture, the daily food ration of animals contained 50 kg of grass, 25 l of river water, and also 1.5 kg of dry mixed fodder at night time.

Cows were milked twice daily (at 7 a.m. and 6 p.m.); the average yield of milk per cow was 10 l. During the fallout period the animals were at pasture. The maintenance regime did not change after the shot.

Milk sampling for radiometry, radiochemistry, and spectrometry analysis started four hours following pasture contamination and was continued for 32 days. During this period the specific activity of milk actually decreased to background values. Milk was sampled after each milking during the first 18 days. Sampling was performed from the total bulk and the samples represented averaged samples for all cows in lactation period. The main results for milk sample measurements are given in Figure 6.

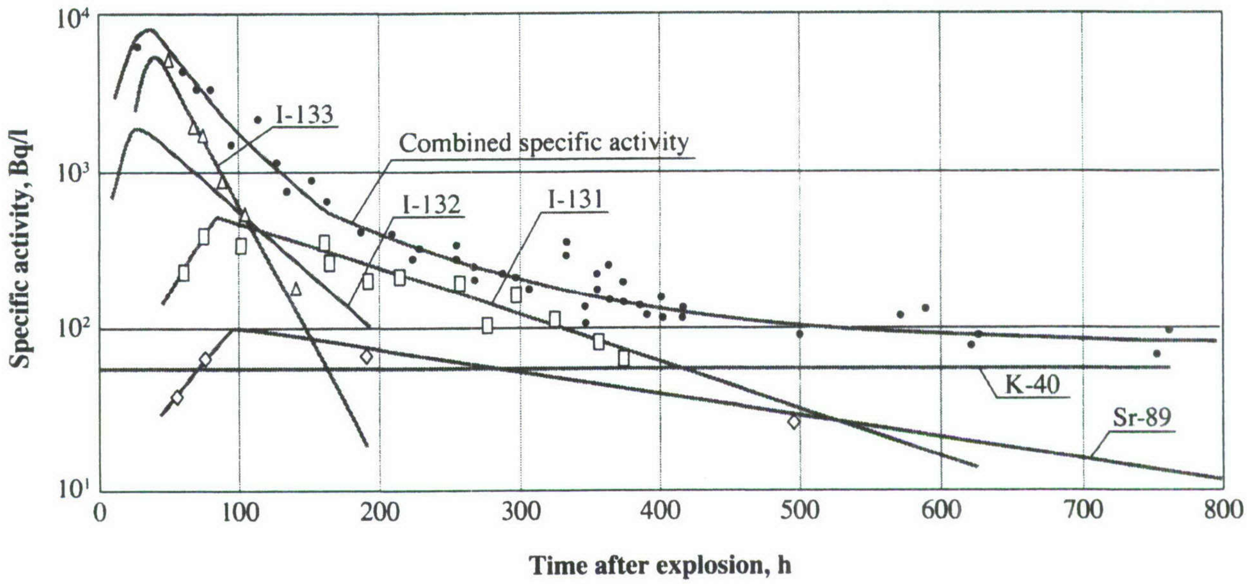

Figure 6. Time variations of specific activity in milk.

Three periods can be distinguished in the variation pattern of radionuclide concentration in milk. The first period is the increased activity in milk that lasted about 1.5 days. During this period the radionuclide concentration in milk grew very rapidly and reached 50% of the maximum value as early as four hours later. The second period demonstrated a relatively fast decrease in milk activity. For 10-11 days of this period the total milk activity decreased by 30-32 times as the short-lived iodine-133 and iodine-132 decayed. The third period involved a monotonic decrease of milk contamination to the natural background activity.

The rate of milk clearing was determined both by the physical decay of radionuclides and other (non-radiological) factors of food clearing. These factors might involve growing of new (fresh) grass and the preference the animals gave to it, as well as the features of the vegetation period. It is important to note that the milk half-clearing periods for pasture-based maintenance were shorter (two to five-fold less) than the half-lives of the corresponding radionuclides.

3.5 INHALATION RISK EVALUATION

The research into radioactive material inhalation hazards was performed with experimental animals, mainly dogs, during the entire period of atmospheric nuclear tests.

From the biological viewpoint the actual inhalation risk is only from radioactive materials residing on particles less than 50 μm in diameter. Radioactive particles of this size can enter the organism through unprotected respiration, remain on the skin and clothing, be eaten by animals together with grass, etc.

For evaluation of inhalation risk, the basic goal was to determine the ratio between quantitative

parameters of animal organism contamination when radioactive materials were inhaled into the respiratory system and when they were ingested with food. The characteristics of surface skin contamination and external irradiation doses in various emergency conditions were also studied.

Inhalation risk from residual radiation in the contaminated zones was estimated during the three most important periods:

- The period of radioactive material fallout from the moving explosion cloud (primary contamination of the near-surface air layer);
- The period, often referred to as secondary dust formation, characterized by transport vehicles (caterpillar and wheel vehicles) crossing the contaminated territory;
- The period of intensive artificial dust formation (secondary natural air contamination from natural wind-driven dust lift), which could contaminate territory beyond the initial contaminated areas (radioactive trace).

Let us consider each of these periods, beginning with the studies during the nuclear materials fallout, i.e., primary air contamination. The difficulty in using animals for studies in the traces from ground surface explosions was that the biological points should be at significant distances from the burst center where the fraction of radioactive materials associated with particles less than 50 μm in diameter is about 50%. Even for medium yield explosions this distance is about 100 km. Since it is very difficult to place the animals in advance at biological points in the radioactive trace, the experiments involving the animals to study the degree of organism injury caused by radioactive fallout was restricted to low and super-low yield explosions.

To prevent the dogs from licking off radioactive materials and neighboring items three ways were used:

- a wide plywood ring on the dog's neck;
- emplacing the dogs in a bedframe with fixed head position;
- use of a special muzzle.

The most convenient way was to use iron-plate muzzles. The muzzle had the form of a concatenated cone with holes 20 mm in diameter along the side surface to allow for air movement. The muzzle was fixed to the collar with breast-bands. With this muzzle the dogs behaved quietly, while they usually tried to throw off the plywood ring.

To avoid additional deposition and removal of radioactive materials on/from the animals during transportation at great distances, the researchers had to kill them at the biological points. Multilayer sacks were used to transport the dog bodies to the laboratory which allowed retention of nuclear materials on the body surface.
The animals were placed on the territory where the radioactive trace formation was expected. Each biological point contained two muzzled dogs. The total number of such points was 15 with the average distance between them about 1 km. Sticky flat tables (a film coated with vinypol dissolved in gasoline) were placed between the biological points. The distance between the tables was 200 m.

The animals were removed and the tables were collected two or three hours after the shot. Measurements were performed for gamma radiation on the ground and soil samples were also obtained for analysis. External radiation doses were determined at different times after the fallout of radioactive materials.

The animals' bodies were carried to the laboratory where their external contamination was measured. During the autopsies samples of several organs and tissues were taken. The tissue samples were dissolved in nitric acid. The lungs, trachea with larynx, and alimentary canal together with its contents were burnt to the ash state in the furnace. The concentration of radioactive materials was determined in all samples. Radiography was performed for the ash obtained from the lungs, trachea with larynx, and alimentary canal to evaluate the size of the radioactive particles.

The dogs' lungs contained 1 microcurie of activity in one of the experiments where the external radiation dose was 0.5 R during the trace formation. The maximum size of radioactive particles inhaled by the dogs was 53 microns. For this type of inhalation effect, the relative penetration of radioactive material to the muzzled dog was on average about 30 microcurie per 1 R of exposure and the surface contamination per R was 0.8 $\mu Ci/cm^2$.

The inhalation risk was studied in the radioactive trace during the time of intensive artificial dust formation. The experiments were carried out as follows. Muzzled dogs were emplaced on open trucks together with sticky flat tables and mannequins in army uniforms. The truck carrying the dogs followed the column consisting of tanks and armored personnel carriers on a road made along the radioactive trace at various ranges from the burst center. Usually the column followed a ring road 300-400 m in radius.

After these convoys of various lengths were terminated, the animals were killed and the bodies were transported to the laboratory. Further studies and measurements were done using the scheme described above. It is interesting that for this type of dust formation the major portion of radioactive materials was found in the alimentary canal rather than in the organs of respiration. The thyroid gland contained a maximum of 0.3%. The average relative penetration of radioactive materials to the animal organism was 4-8 microcurie/R and the surface contamination per R was 0.08-0.2 microcurie/cm^2.

The radioactive contamination of the body surface (hair and skin) was about two times higher than that of the mannequins' uniforms and was nearly comparable with the contamination level of sticky flat tables.

The results of these studies allowed us to conclude that under strong visually observable dust formation the injurious effect of contact skin exposure can dominate over external gamma radiation effect. The evaluation of hazard resulting from natural dust formation (wind-driven dust lift) used the dogs emplaced in the frames with fixed heads. DKR-50 dosimeters were

installed near them. This gave the data indicating that under natural dust formation the relative penetration of radioactive materials into the animal's body was 0.10-0.15 microcurie/R and the contamination of the body surface per R was $5 \cdot 10^{-3}$ μCi/cm^2.

The experiments for the inhalation risk evaluation used about 50 male and female mongrel dogs with an average weight of 12.6 kg. The main conclusion of the risk evaluation experiments was that elementary protection means for the respiration organs (such as respirators) are relatively efficient and can be used in emergencies.

In addition to dogs and larger animals, the experiments for the studies of nuclear weapon injurious effects also used small laboratory animals such as rats and mice. They were extensively used to study the migration processes of nuclear explosion products and various radionuclides over the biological chains. Due respect should be given to the animals of all types, and especially to dogs, that were and still remain the main assistants in experimental research, not only in radiobiology but also in medicine in general.

3.6 CONCLUSIONS

The research efforts for the subject, *"Animal Effects from Soviet Atmospheric Nuclear Tests,"* were performed in strict accordance with the task order under the contract DNA 001-095-C-0157 of July 12, 1995. This report generalizes the data from medical and biological studies describing the impact features of atmospheric nuclear explosion injurious effects, particularly blast effects, thermal radiation, penetrating (primary) ionizing radiation, and radioactive territory contamination (secondary radiation).

The first part of this report contains the basic results of analysis of experimental data on the blast and thermal radiation effects on animals. To study the biological effects, the animals were placed on the open ground, in field and permanent structures, in military materiel items, as well as in residential and industrial buildings of various types. The experimental data obtained from ground surface and atmospheric low, medium and high yield nuclear explosions were used to determine the size of the damage zones in terms of animal disease levels.

The second part of this report presents the generalized results from the experimental data on the impact of penetrating radiation on animals, both for radiation effects alone and combined effect, and describes the basic injury types that can occur in the radioactive fallout traces after ground surface nuclear explosions.

It should be particularly noted that the medical and biological program for investigating the injurious effects from nuclear explosions was developed and implemented in the former Soviet Union and was focused primarily on penetrating radiation. First, prior to the emergence of nuclear weapons, neither scientists nor practical workers were aware of the mass casualty factor. Second, no complete understanding existed for physical laws governing the formation and propagation of the basic penetrating radiation components in the environment, and no required data were available for the clinical pattern of the radiation disease and treatment methods in the event of massive injuries. Third, no data existed for combined (radiological-thermal and radiological-mechanical) effects typical for nuclear weapons. We omit purely physical aspects of this problem relating to the development of radiometry and dosimetry devices.

When generalizing the existing data, special attention was given to the analysis results for the recommendations on how to treat ARD and some combined injuries. These recommendations were developed from data obtained using experimental animals. The sections of the report devoted to these issues contain a relatively detailed research analysis obtained from the medical and biological programs during atmospheric nuclear testing.

Important results were obtained from the investigations of radioactive fallout (residual radiation) as it affects animals. Primarily this relates to the studies of radioactive fallout itself (particles carrying radionuclides). Without these data it would be impossible to study impact of radioactive fallout on the body. We believe that the data on milk contamination obtained from sampling analysis of a cow herd, described in the final chapter of this report, is of great interest. In

addition, this section contains the estimate of risk for inhaled radioactive materials.

Thus, the experiments involving animals within the medical and biological programs studied the impacts of nuclear explosion injurious effects on the organism and allowed us to develop recommendations for medical triage and treatment of affected individuals.

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